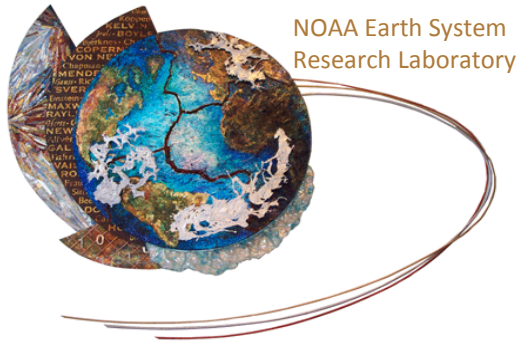
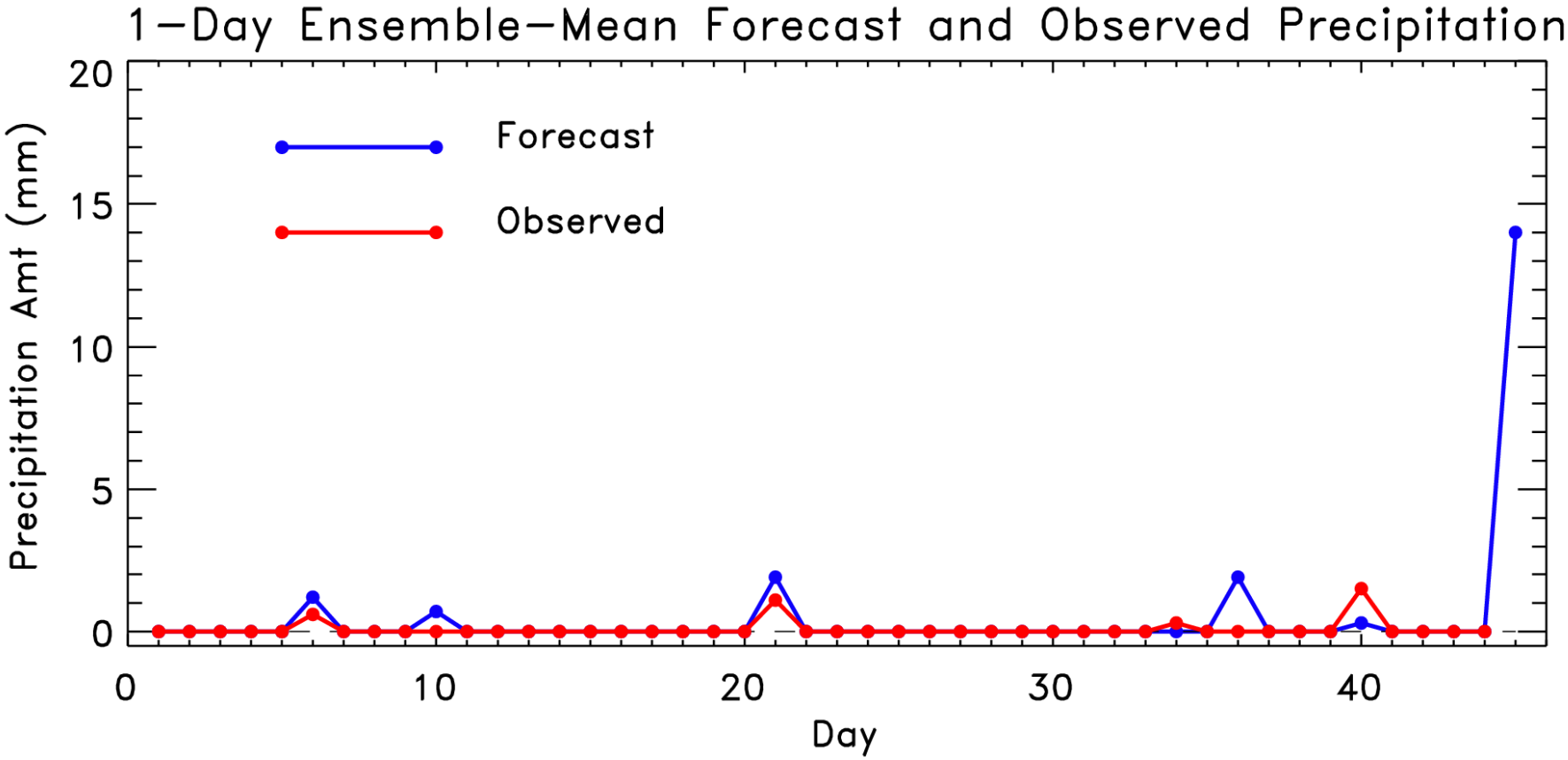


Experimental statistically post-processed guidance based on the NCEP GEFS reforecasts.

Tom Hamill and Gary Bates
NOAA ESRL, Physical Sciences Division
tom.hamill@noaa.gov

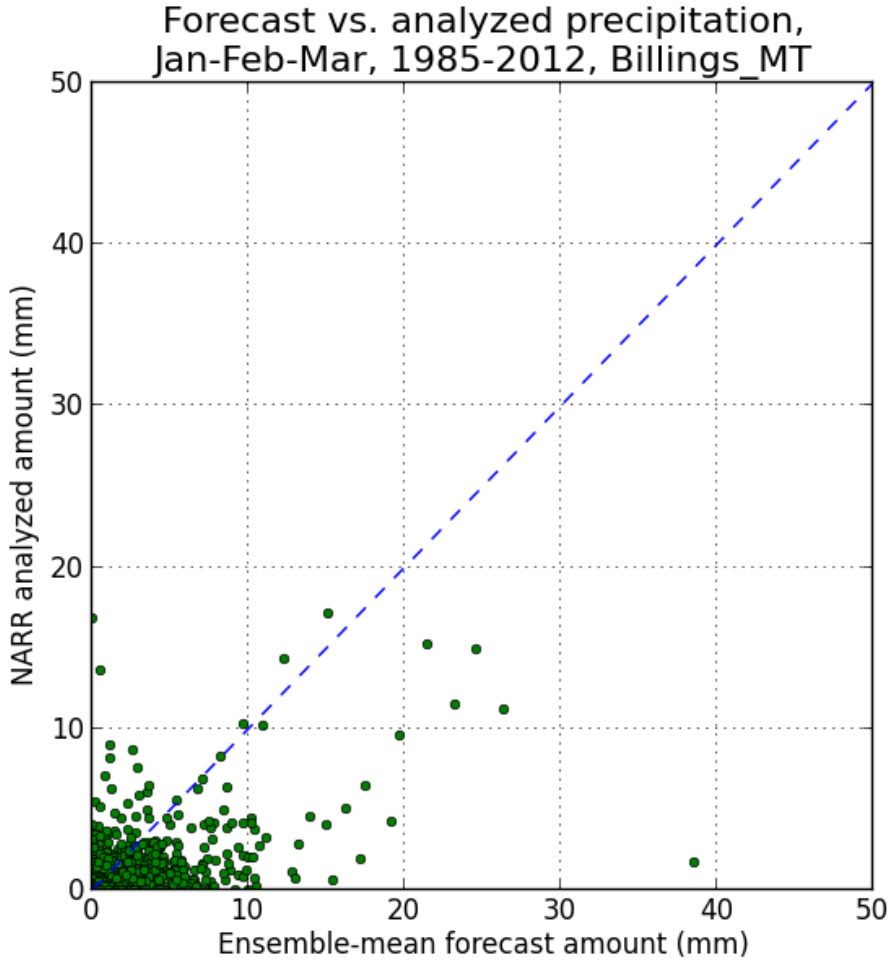
also: Jeff Whitaker, Don Murray, Francisco Alvarez, Mike Fiorino, Tom Galarneau

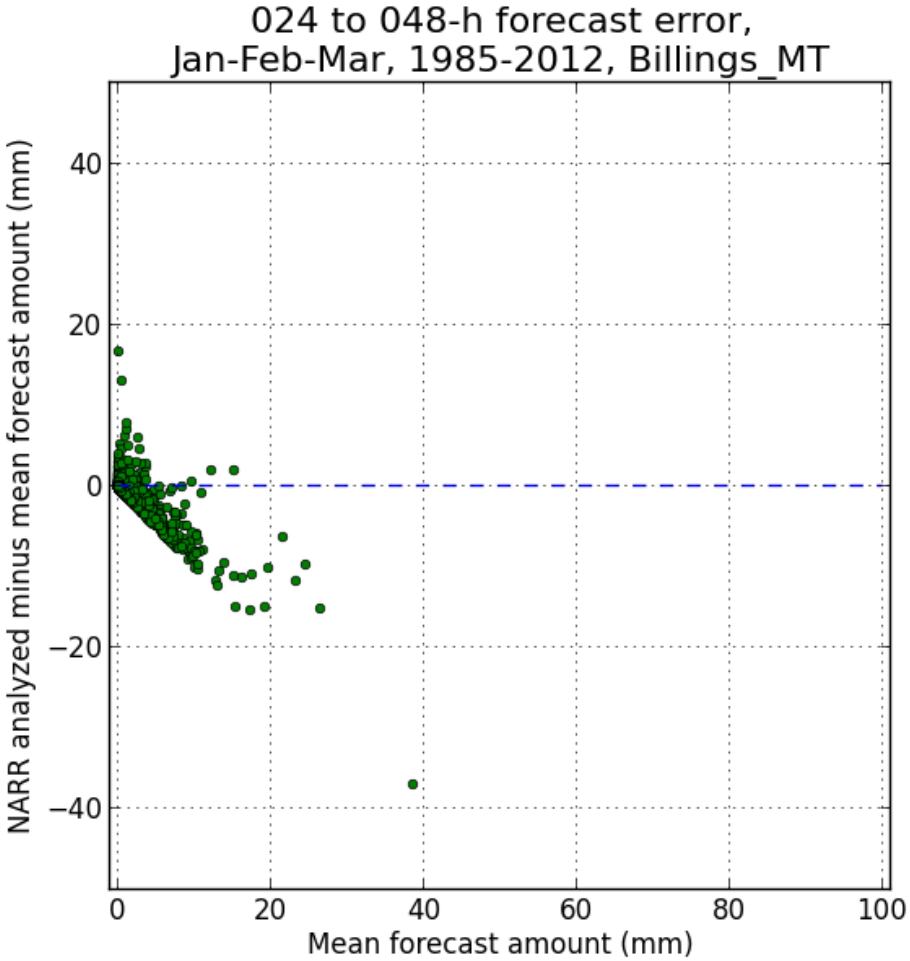
Reminder: statistical post-processing for rare events is challenging without a large training sample



Say you want to statistically post-process today's model precipitation forecast to improve it. Heavy precipitation events like the one today are the ones you care about the most. How do you calibrate today's forecast given past short sample of forecasts and observations?

Example of forecast / analysis data





Assuming forecast errors may be location dependent, it's helpful to have a lot of samples in order to post-process these rare events.

Reforecasts (hindcasts)

- Numerical simulations of the past weather (or climate) using the same forecast model and assimilation system that (ideally) is used operationally.
  - Common with climate, uncommon with weather models.

2nd-generation GEFS reforecast: details

- Seeks to mimic GEFS operational configuration as of February 2012. This version still operational, though data assimilation method was improved in May 2012.
- Reforecasts produced every day, for 1984120100 to current.
- Each 00Z, 11-member forecast, 1 control + 10 perturbed.
- CFSR (NCEP's Climate Forecast System Reanalysis) initial conditions (3D-Var) + ETR perturbations (cycled with 10 perturbed members). After ~ 22 May 2012, initial conditions from hybrid EnKF/3D-Var.
- Resolution: T254L42 to day 8, T190L42 from days 7.5 to day 16.
- Fast data archive at ESRL of 99 variables, 28 of which stored at original ~1/2-degree resolution during week 1. All stored at 1 degree. Also: mean and spread to be stored.
- Full archive at DOE/Lawrence Berkeley Lab, where data set was created under DOE grant.

Status of the reforecast v2 archive.

- 00Z reforecast data and (since mid-2012) 00Z GEFS real-time forecasts are publicly available from our archive.
- Download web sites are open to you now:
  - NOAA/ESRL site: fast access, limited data (99 fields). Also there, README & info on how to ftp.
    - http://www.esrl.noaa.gov/psd/forecasts/reforecast2/
  - US Department of Energy: slow access, but full model states. Recent months not uploaded yet.
    - http://portal.nersc.gov/project/refcst/v2/

Data that is readily available from ESRL

Table 1: Reforecast variables available for selected mandatory and other vertical levels. Φ indicates geopotential height, and an X indicates that this variable is available from the reforecast data set at 1-degree resolution; a Y indicates that the variable is available at the native ~0.5 degree resolution. AGL indicates "above ground level."

Vertical Level	U	V	T	Φ	q	Wind Power
10 hPa	X	X	X	X		
50 hPa	X	X	X	X		
100 hPa	X	X	X	X		
200 hPa	X	X	X	X		
250 hPa	X	X	X	X		
300 hPa	X	X	X	X	X	
500 hPa	X	X	X	X	X	
700 hPa	X	X	X	X	X	
850 hPa	X	X	X	X	X	
925 hPa	X	X	X	X	X	
1000 hPa	X	X	X	X	X	
$\sigma \cong 0.996$	X	X		X		
$\sigma \cong 0.987$	X	X		X		
$\sigma \cong 0.977$	X	X		X		
$\sigma \cong 0.965$	X	X		X		
80m AGL	X,Y	X,Y				X,Y

Also: hurricane track files and other hurricane diagnostic information

Data that is readily available from ESRL

Variable (units)
Mean sea-level pressure (Pa) [Y]
Skin temperature (K) [Y]
Soil temperature, 0.0 to 0.1 m depth (K) [Y]
Volumetric soil moisture content 0.0 to 0.1 m depth (fraction between wilting and saturation) [Y]
Water equivalent of accumulated snow depth (kg m^{-2}, i.e., mm) [Y]
2-meter temperature (K) [Y]
2-meter specific humidity (kg kg^{-1} dry air) [Y]
Maximum temperature (K) in last 6-h period (00, 06, 12, 18 UTC) or in last 3-h period (03, 09, 15, 21 UTC) [Y]
Minimum temperature (K) in last 6-h period (00, 06, 12, 18 UTC) or in last 3-h period (03, 09, 15, 21 UTC) [Y]
10-m u wind component (ms^{-1}) [Y]
10-m v wind component (ms^{-1}) [Y]
Total precipitation (kg m^{-2}, i.e., mm) in last 6-h period (00, 06, 12, 18 UTC) or in last 3-h period (03, 09, 15, 21 UTC) [Y]
Water runoff (kg m^{-2}, i.e., mm) [Y]
Average surface latent heat net flux (W m^{-2}) [Y]
Average sensible heat net flux (W m^{-2}) [Y]
Average ground heat net flux (W m^{-2}) [Y]
Convective available potential energy (J kg^{-1}) [Y]

Convective inhibition (J kg^{-1}) [Y]
Precipitable water (kg m^{-2}, i.e., mm) [Y]
Total-column integrated condensate (kg m^{-2}, i.e., mm) [Y]
Total cloud cover (%)
Downward short-wave radiation flux at the surface (W m^{-2}) [Y]
Downward long-wave radiation flux at the surface (W m^{-2}) [Y]
Upward short-wave radiation flux at the surface (W m^{-2}) [Y]
Upward long-wave radiation flux at the surface (W m^{-2}) [Y]
Upward long-wave radiation flux at the top of the atmosphere (W m^{-2}) [Y]
Potential vorticity on the 320K isentropic surface (×10-6 K m^2 kg^{-1} s^{-1})
U component on 2 PVU (1 PVU = 1×10-6 K m^2 kg^{-1} s^{-1}) isentropic surface (ms^{-1})
V component on 2 PVU isentropic surface (ms^{-1})
Temperature on 2 PVU isentropic surface (K)
Pressure on 2 PVU isentropic surface (Pa)
80-m u wind component (ms^{-1}) [Y]
80-m v wind component (ms^{-1}) [Y]
Vertical velocity at 850 hPa (Pa s^{-1})
Water runoff (kg m^{-2}, i.e., mm)
Wind mixing energy at 80 m (J) [Y]

[Y] indicates that this variable is available at the native ~0.5-degree resolution as well as the 1-degree resolution.

http://esrl.noaa.gov/psd/forecasts/reforecast2/download.html

Select Desired Variables and Associated Levels:

Single Level (1°x1°) | Pressure Levels (1°x1°) | Hybrid Levels (1°x1°) | Single Level (Gaussian ~.5°)

- Total Accumulated Precipitation
- U-Component of Wind at 10 meters
- U-Component of Wind at 80 meters
- Convective Available Potential Energy
- Surface Downward Long-Wave Radiation Flux
- Surface Upward Long-Wave Radiation Flux
- Ground Heat Flux
- Surface Sensible Heat Net Flux
- Surface Pressure
- Volumetric Soil Moisture Content
- Total Cloud Cover
- Skin Temperature
- Minimum Temperature
- Upward Long-Wave Radiation Flux
- Water Equivalent of Accumulated Snow Depth
- Vertical Velocity at 850 hPa Surface
- Pressure on 2 PVU Surface
- V-Component of Wind on 2 PVU Surface
- Temperature at 2 meters
- V-Component of Wind at 10 meters
- V-Component of Wind at 80 meters
- Convective Inhibition
- Surface Downward Short-Wave Radiation Flux
- Surface Upward Short-Wave Radiation Flux
- Surface Latent Heat Net Flux
- Mean Sea Level Pressure
- Precipitable Water
- Specific Humidity at 2 meters
- Total Column-Integrated Condensate
- Maximum Temperature
- Soil Temperature (0-10 cm below surface)
- Water Runoff
- Wind Mixing Energy
- Temperature on 2 PVU Surface
- U-Component of Wind on 2 PVU Surface
- Potential Vorticity on 320 K Isentrope

Select Desired Dates (Available from Dec 1 1984 to Dec 31 2010):

From: **To:**

- Download all the forecasts within the chosen time period. Help
- Download forecasts within the month-days range for the chosen years. Help

Select Desired Forecast Hour(s):

High Resolution: (Select All or Clear)

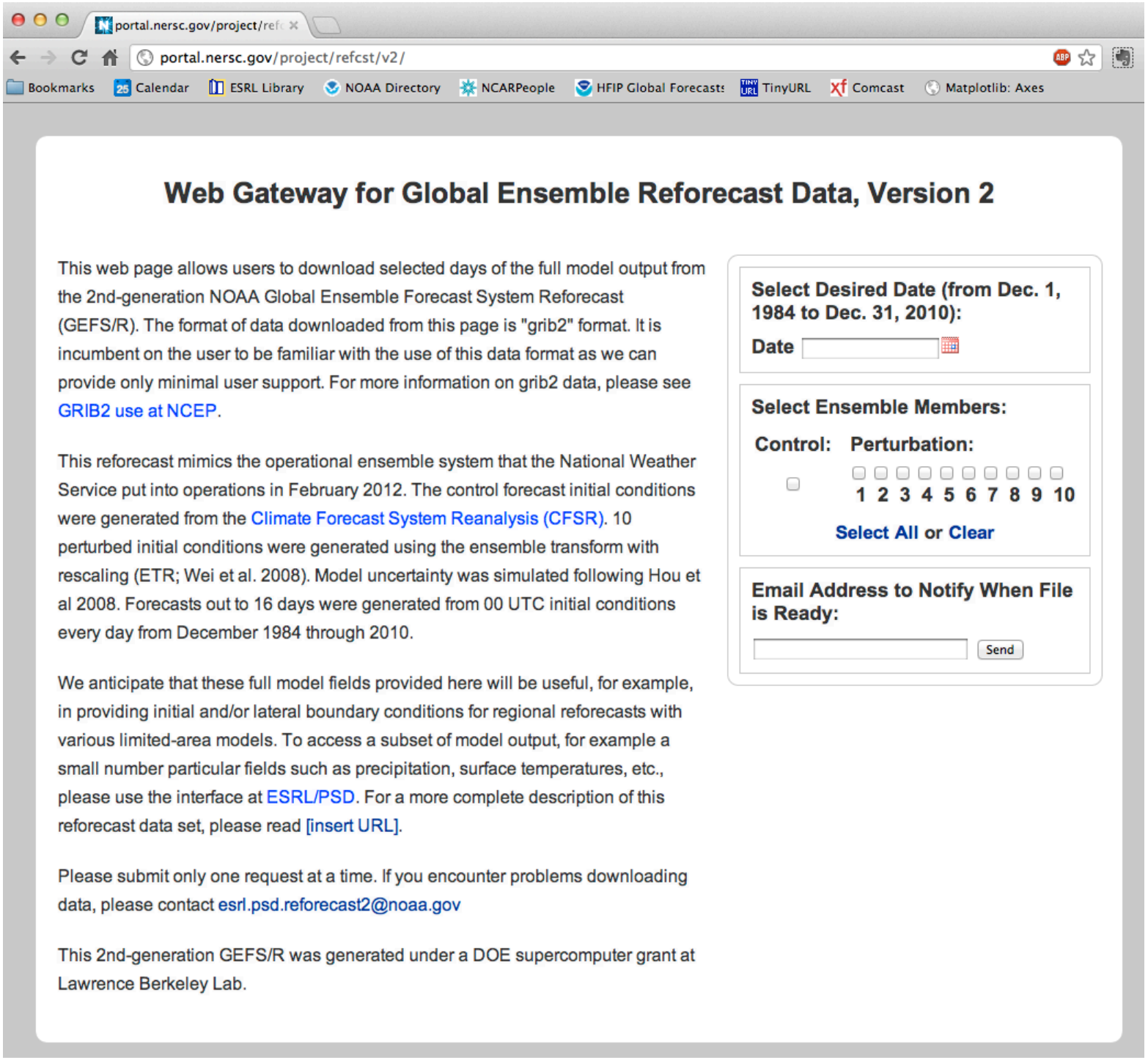
0	3	6	9	12	15	18	21	24	27
30	33	36	39	42	45	48	51	54	57
60	63	66	69	72	78	84	90	96	102
108	114	120	126	132	138	144	150	156	162
168	174	180	186	192					

Low Resolution: (Select All or Clear)

186	192	198	204	210	216	222	228	234	240
246	252	258	264	270	276	282	288	294	300
306	312	318	324	330	336	342	348	354	360
366	372	378	384						

Produces netCDF files.

Also: direct ftp access to allow you to download the raw grib files.

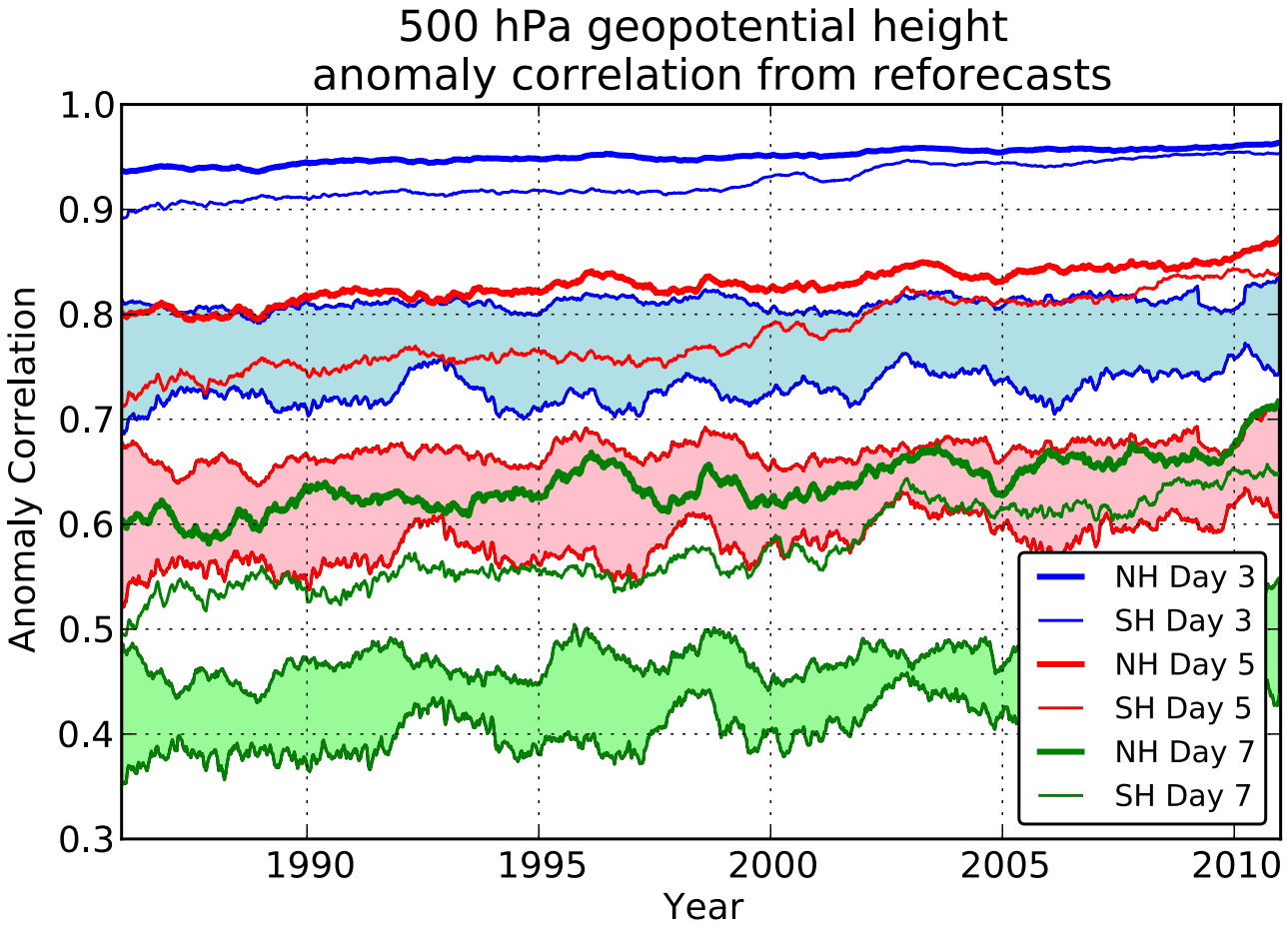


This DOE site permits access to tape storage of full data (slower).

Use this to access full model state, e.g., to initialize and provide lateral boundary conditions to run WRF on an old case.

Skill of the raw reforecasts (no post-processing)

500 hPa Z anomaly correlation
(from deterministic control)

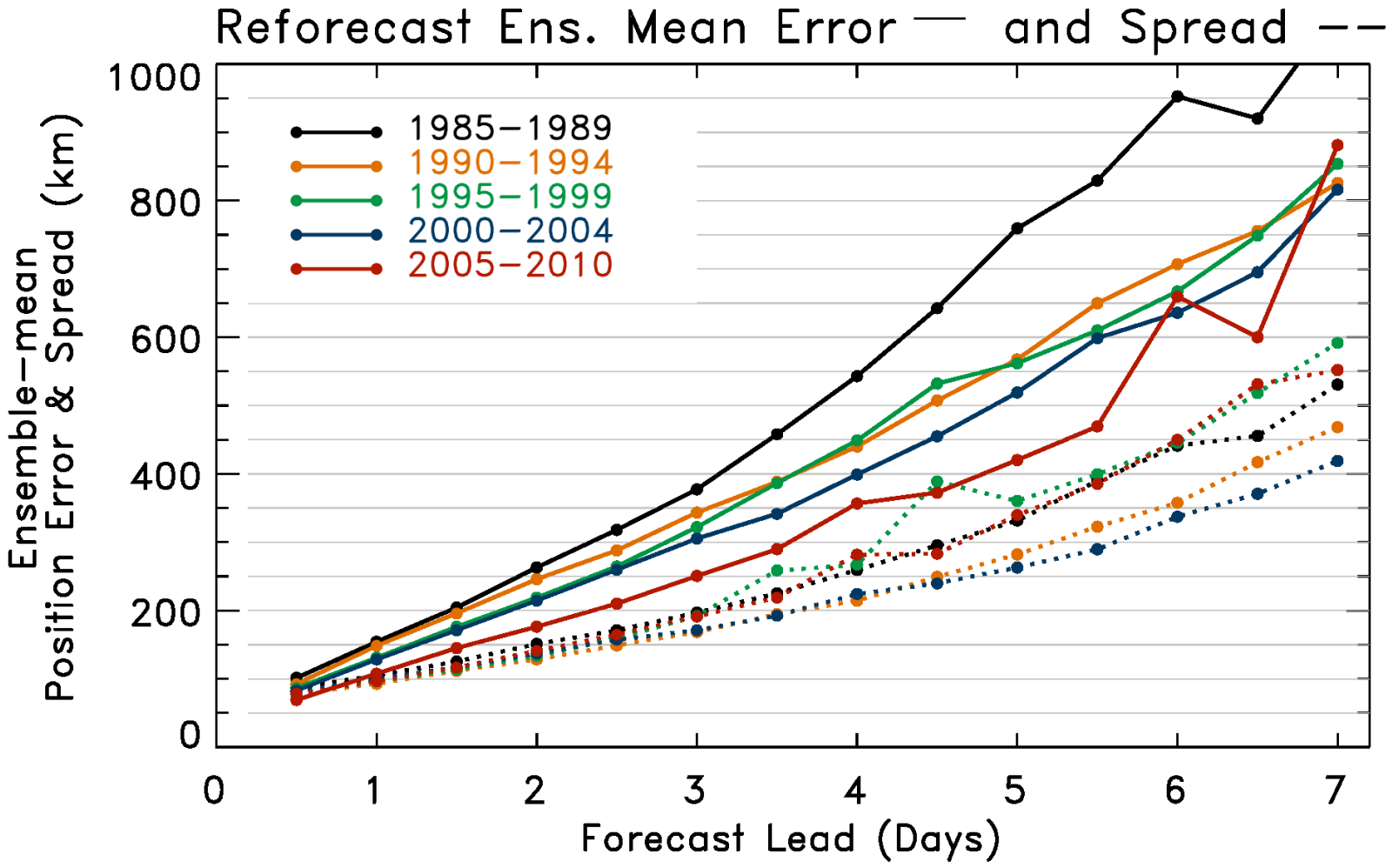


Lines w/o filled colors for second–generation reforecast (2012, T254)

Lines with filled colors for first-generation reforecast (1998, T62).

Perhaps a 1.5-2.5 day improvement.

Tropical cyclone track errors



Less statistical consistency of errors over the period of the reforecasts, as opposed to 500 hPa anomaly correlation, which emphasizes mid-latitude variability.

Madden-Julian Oscillation (MJO) deterministic verification metrics

$$\mathrm{COR}(\tau) = \frac{\sum_{i=1}^{N} [a_{1i}(t)b_{1i}(t) + a_{2i}(t)b_{2i}(t)]}{\sqrt{\sum_{i=1}^{N} [a_{1i}^2(t) + a_{2i}^2(t)]}\sqrt{\sum_{i=1}^{N} [b_{1i}^2(t) + b_{2i}^2(t)]}},$$

where $a_{1i}(t)$ and $a_{2i}(t)$ are the observed RMM1 and RMM2 at day t, and $b_{1i}(t)$ and $b_{2i}(t)$ are their respective forecasts, for the ith forecast with a τ-day lead. Here, N is the number of forecasts.

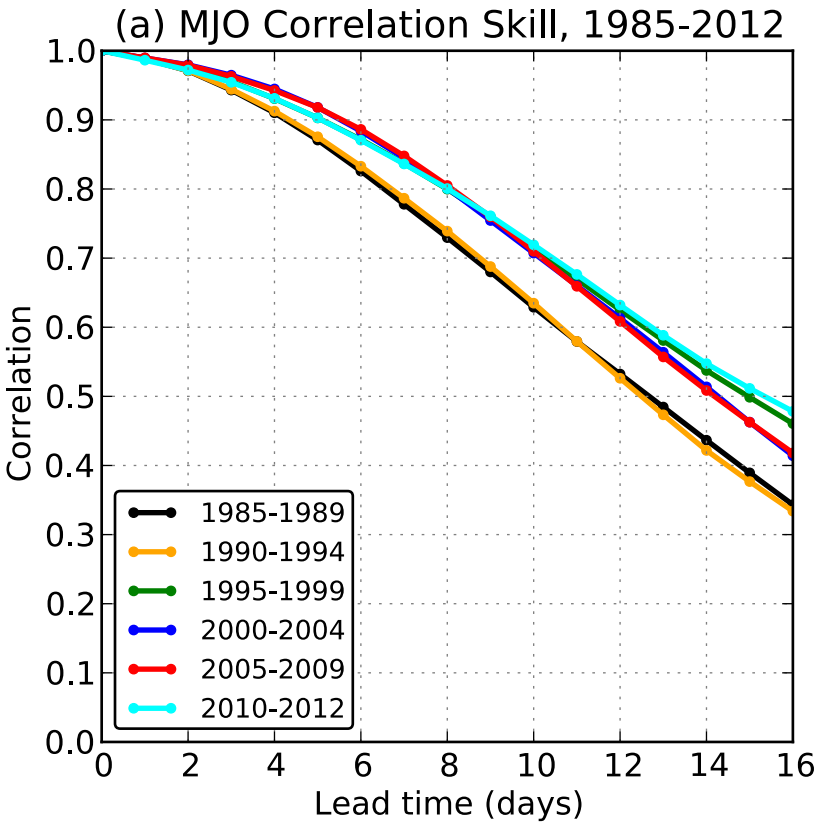
COR(τ) measures the skill in forecasting the phase of the MJO, which is insensitive to amplitude errors. COR(τ) is equivalent to a spatial pattern correlation between the observations and the forecasts when they are expressed by the two leading combined EOFs.

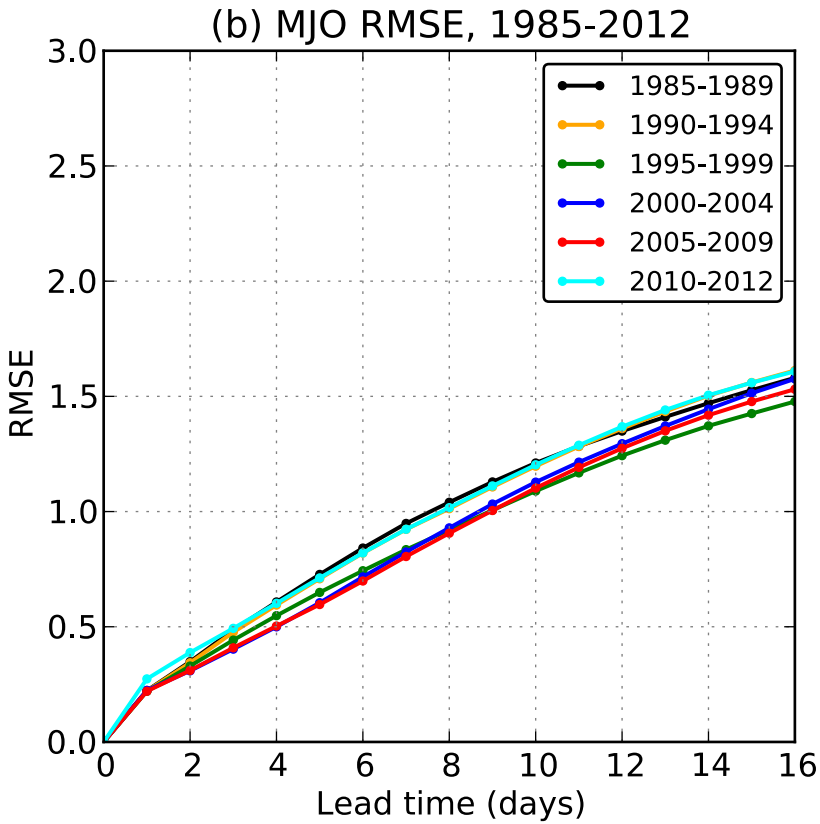
$$\mathrm{RMSE}(\tau) = \sqrt{\frac{1}{N}\sum_{i=1}^{N} \{[a_{1i}(t) - b_{1i}(t)]^2 + [a_{2i}(t) - b_{2i}(t)]^2\}}.$$

RMM1 (= a_1) and RMM2 (= a_2) measure the projection onto the first two principal components of MJO variability.

from Lin et al., Nov 2008 *MWR*.

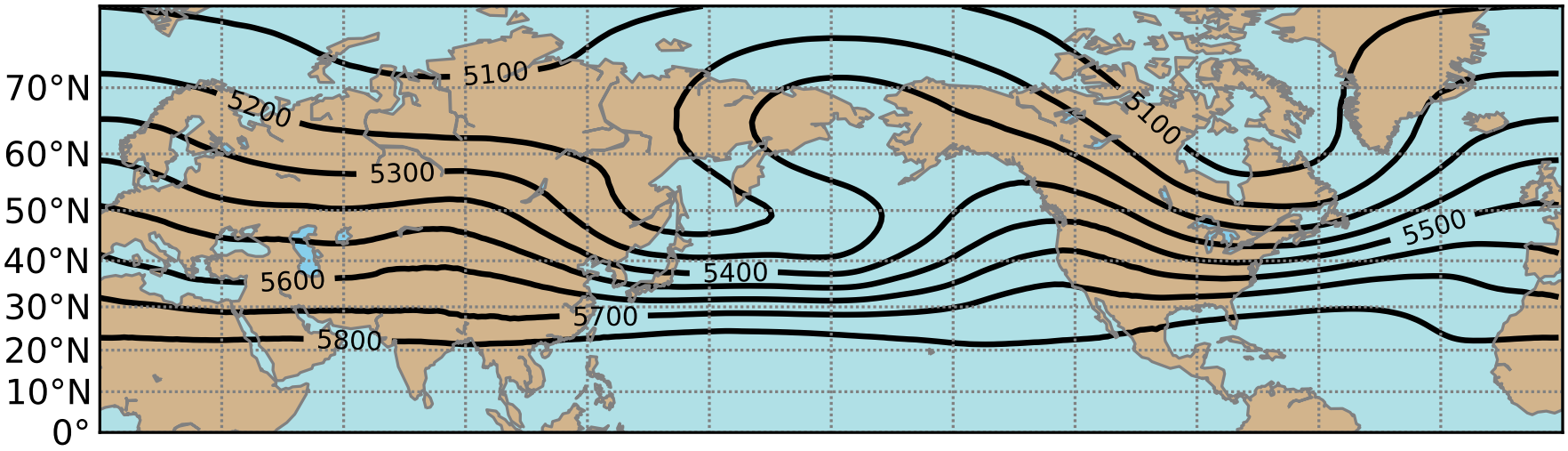
MJO: Bi-variate RMM1 and RMM2 correlation and RMSE by half decade



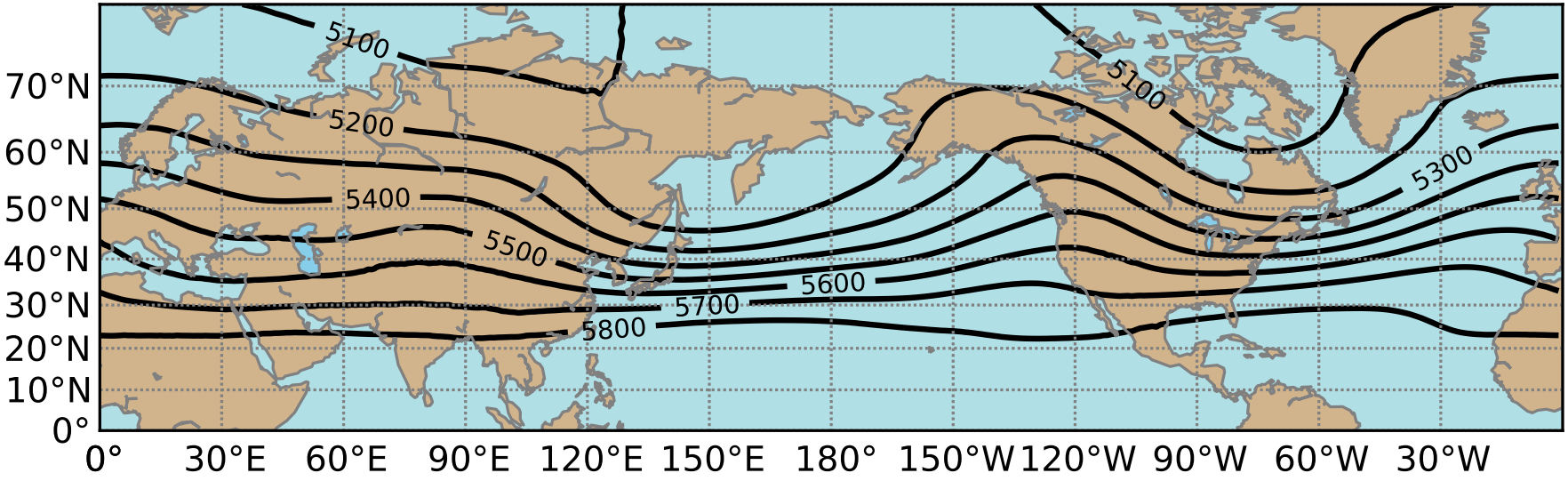


The first 10 years are much less skillful than the subsequent 18.

(a) Composite 500 hPa geopotential height under block at Lon = 180E

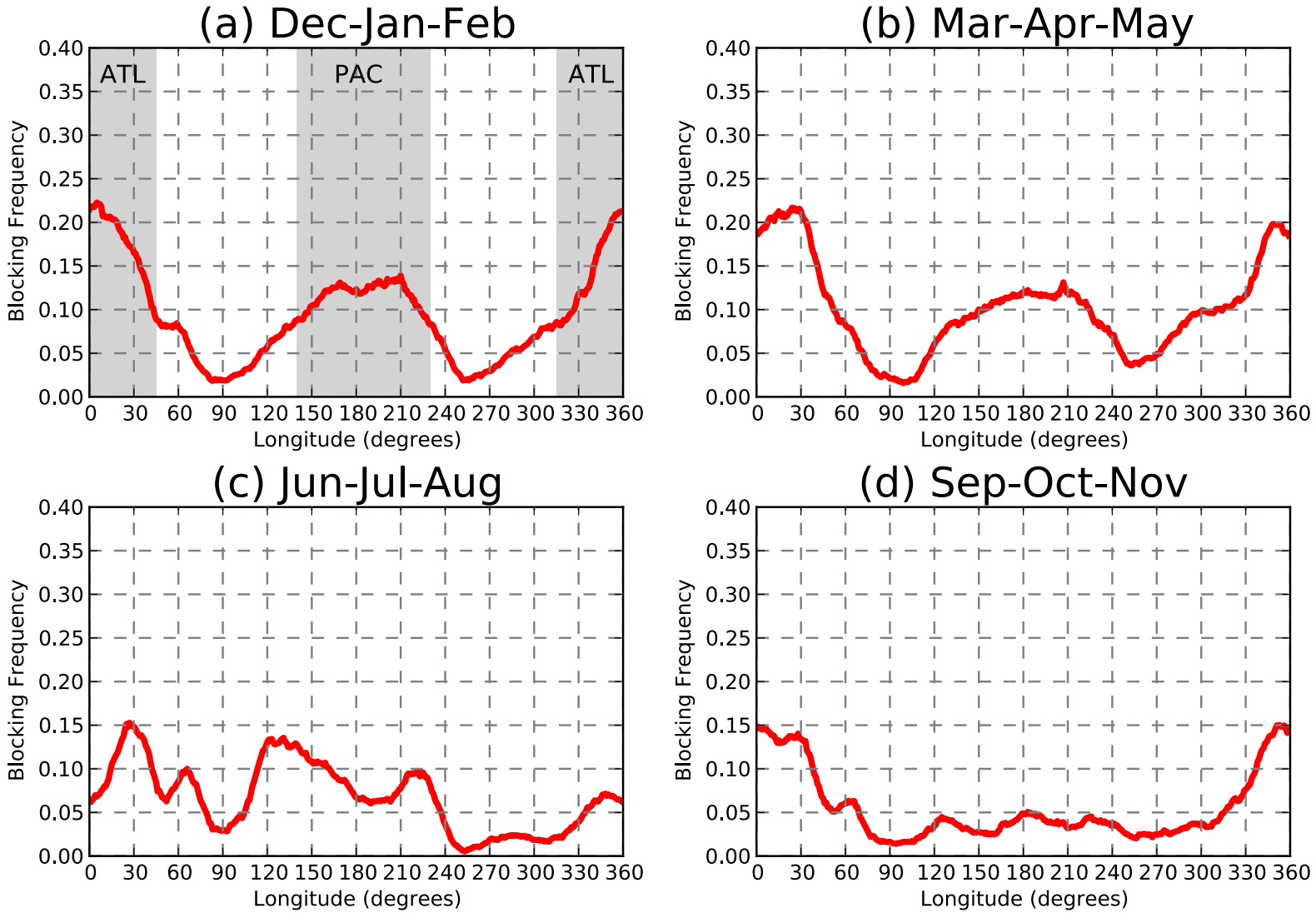


(b) Composite 500 geopotential height under no block at Lon = 180E



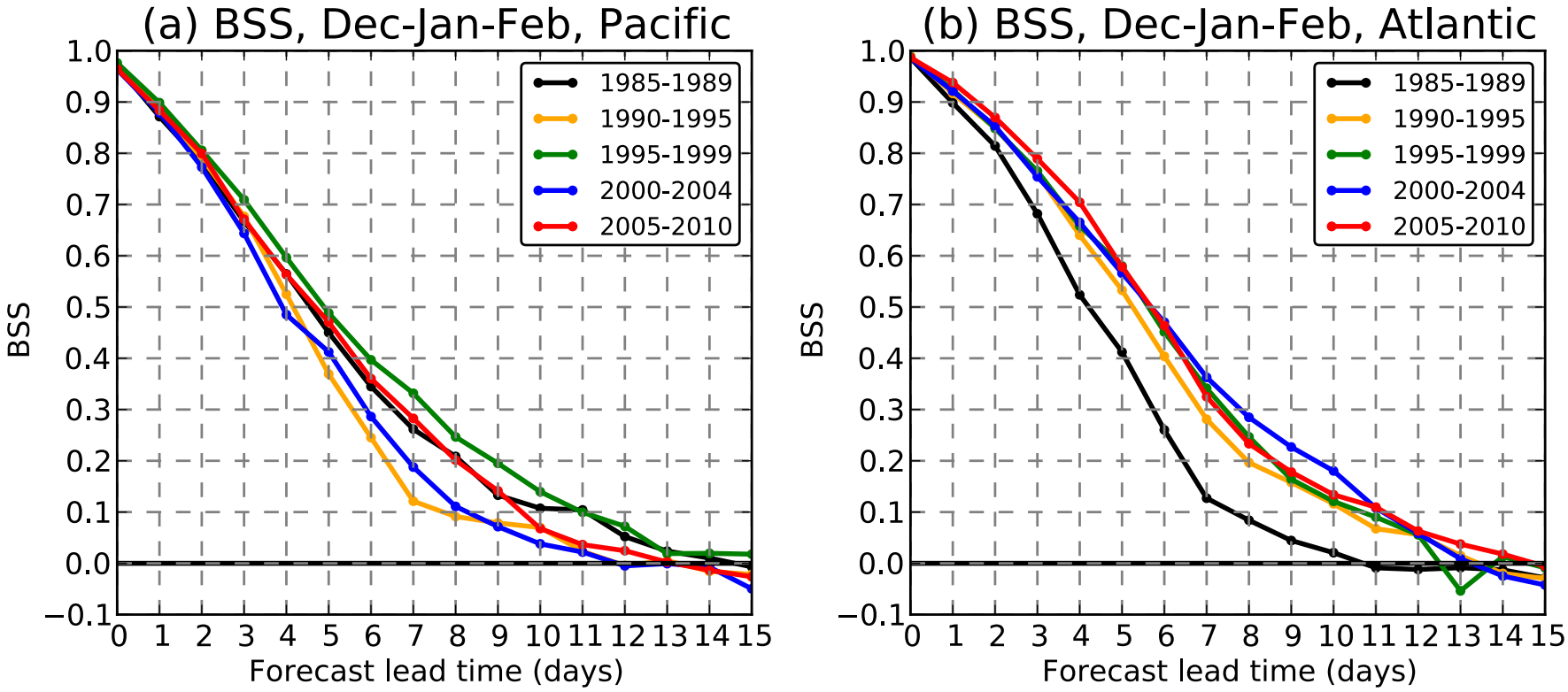
Dec-Jan-Feb 1985-2010 CFSR data. Blocks defined here by Tibaldi/Molteni algorithm.

N Hem. blocking: more common in winter, spring



Blocking as defined in Tibaldi and Molteni (1990) using Z500. In next slide, we focus on Dec-Jan-Feb. Grey bands defines Euro/Atlantic and Pacific blocking sectors in subsequent plots.

GEFS blocking skill by half decade



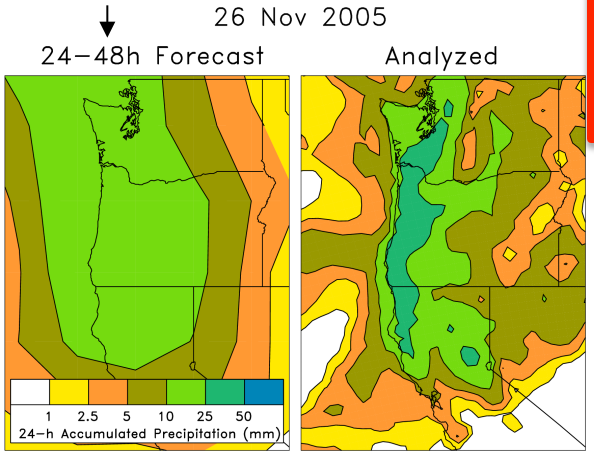
Blocking is evaluated using Tibaldi-Molteni algorithm for every longitude, every day. Skill of the ensemble in predicting blocking is then evaluated.

Decreased Atlantic sector skill in 1985-1989 period stands out.

Statistical post-processing using reforecasts

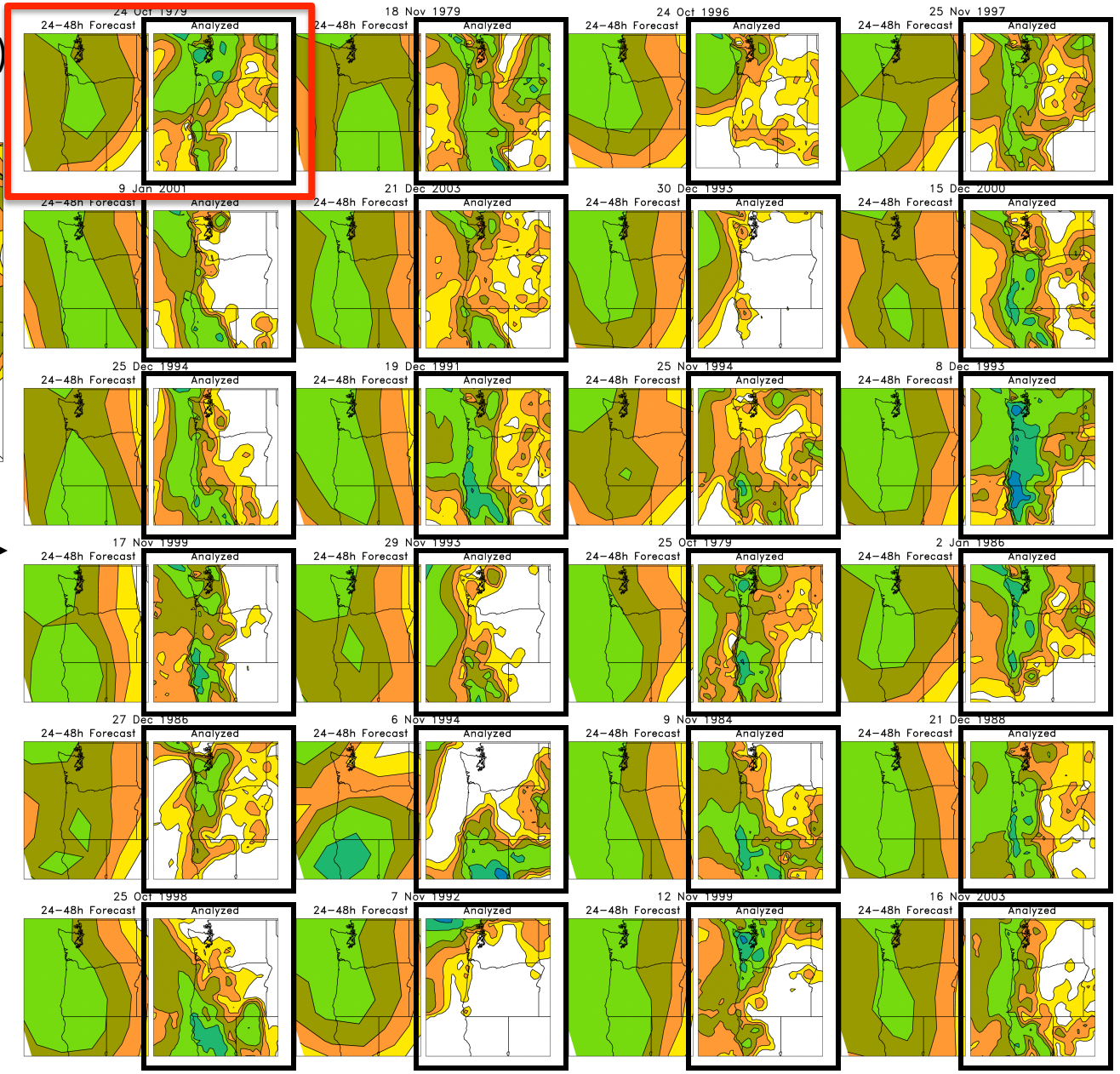
An example of a statistical correction technique using those reforecasts

Today's forecast (& observed)

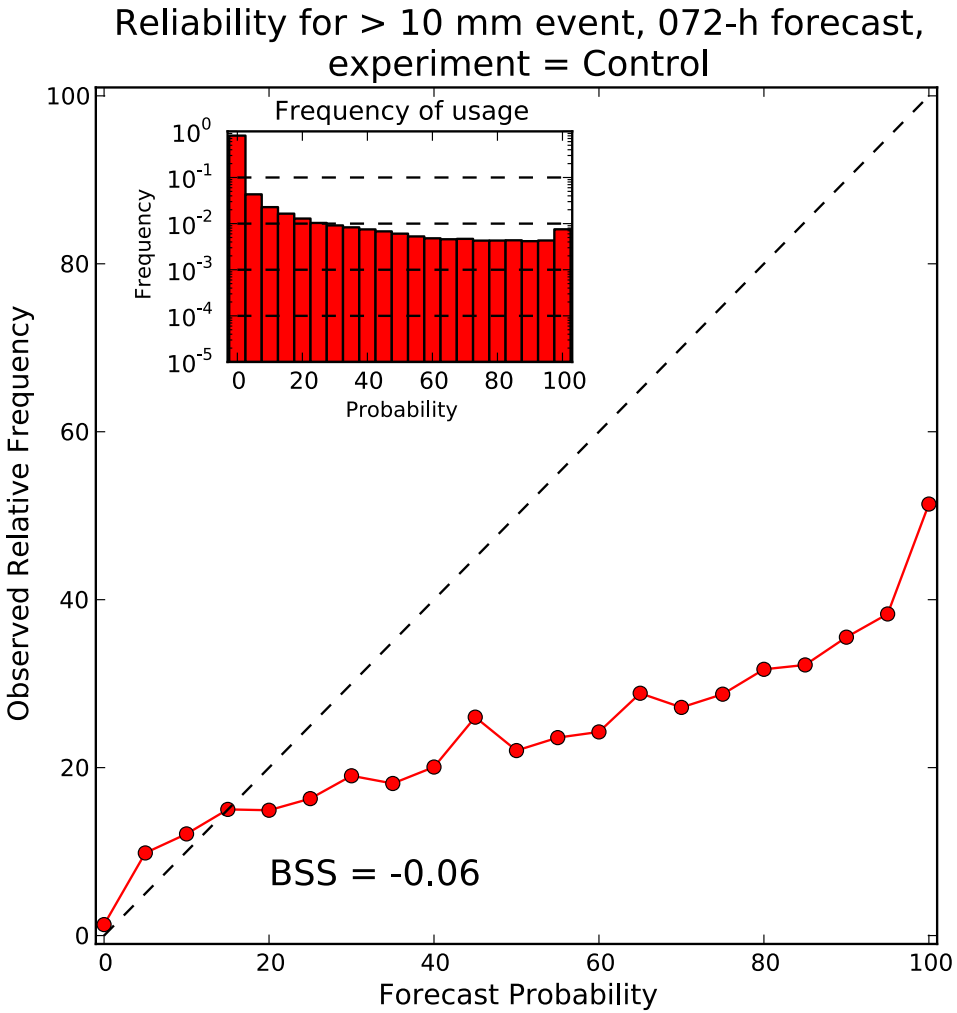


For each pair (e.g. red box), on the left are old forecasts that are somewhat similar to this day's ensemble-mean forecast. The boxed data on the right, the analyzed precipitation for the same dates as the chosen analog forecasts, can be used to statistically adjust and downscale the forecast.

Analog approaches like this may be particularly useful for hydrologic ensemble applications, where an ensemble of weather realizations is needed as inputs to a hydrologic ensemble streamflow system.



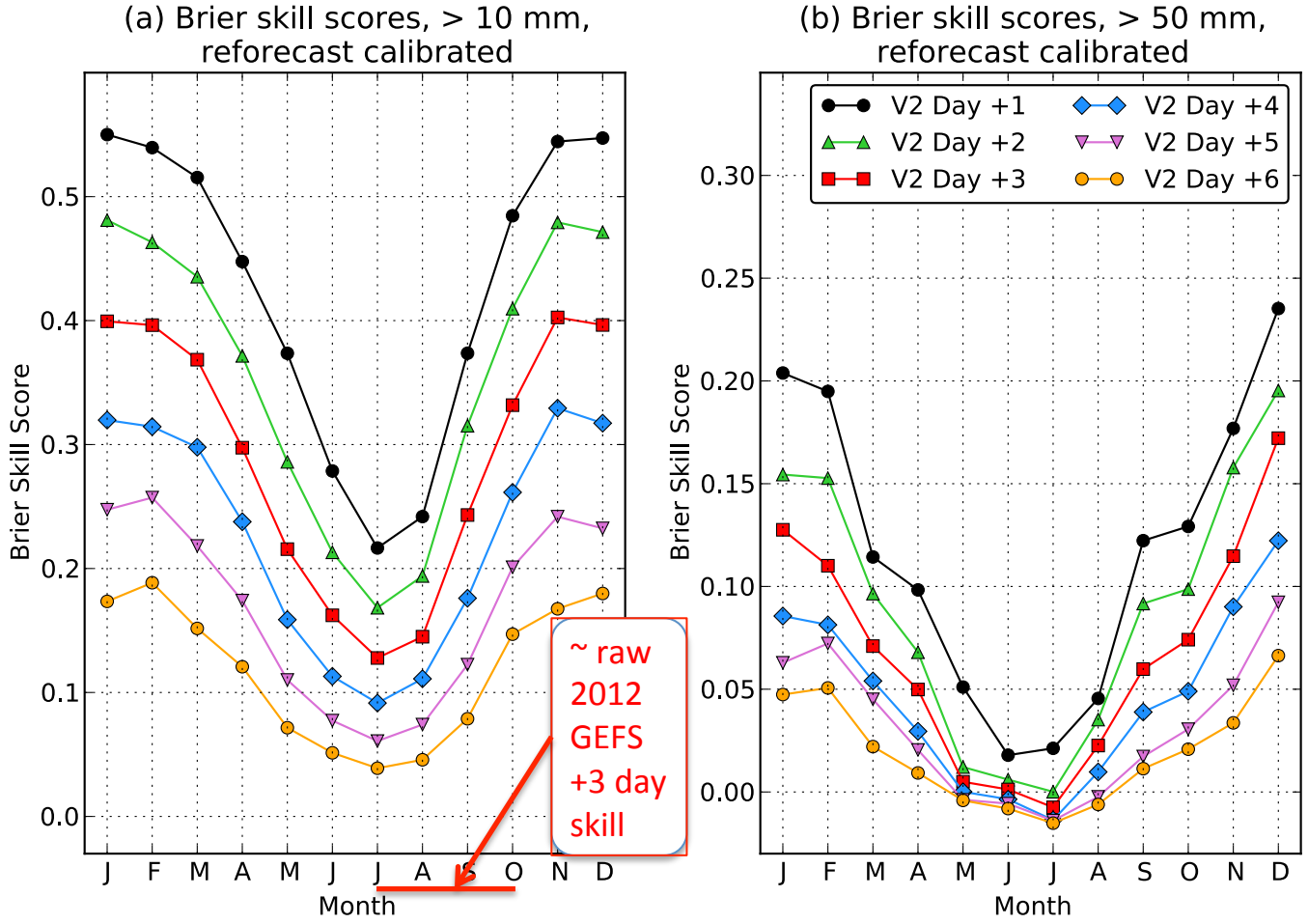
Forecasts evaluated operational 2012 GEFS for 2 Jul – 30 Sep 2012 (against CCPA analyses)



Here, the 21-member ensemble forecasts are validated against the 1-degree NCEP CCPA precipitation analysis, which regresses Stage IV data against the Higgins precipitation analysis.

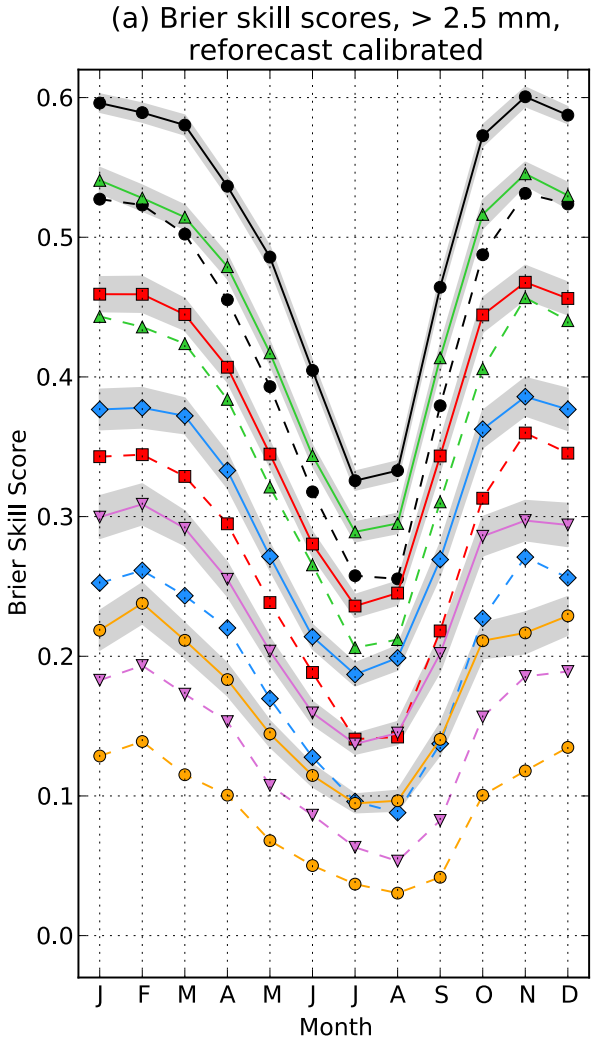
Skill of calibrated precipitation forecasts

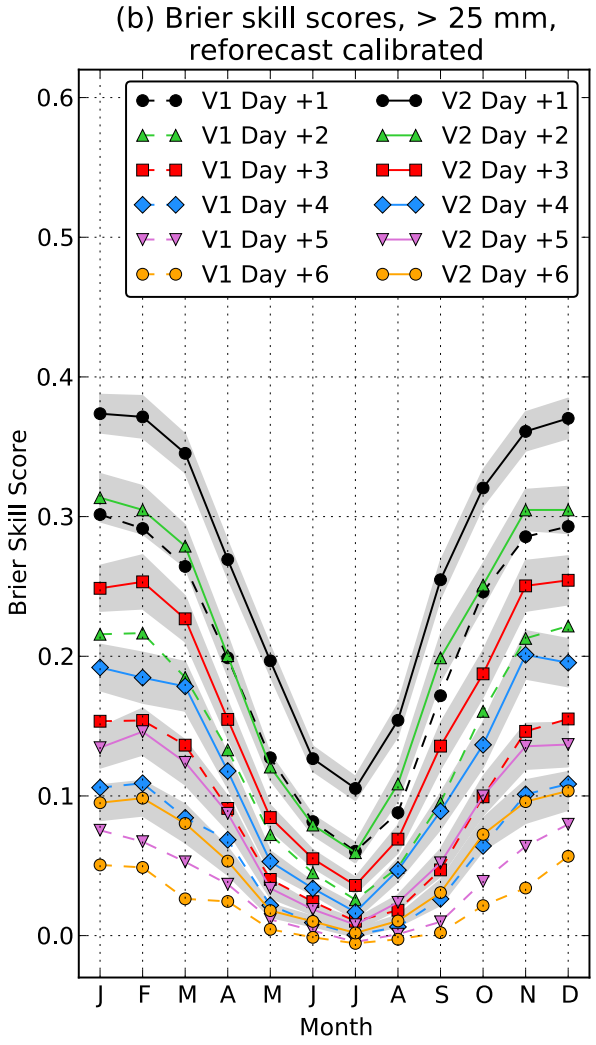
(over US, 1985-2010, "rank analog" calibration method)



Verification here against 32-km North American Regional Reanalysis (tougher).
Verification in previous plot against 1-degree NCEP precipitation analysis (easier).

How do v2 2012 reforecast-calibrated precipitation forecasts compare to the v1, 1998 reforecast-calibrated?





solid lines are reforecasts from the 2012 GEFS

dashed lines are reforecasts from the 1998 GEFS

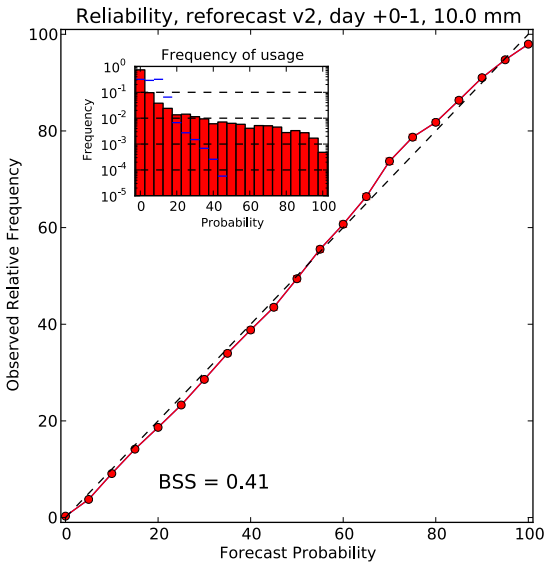
gray bars are the 5-95% confidence intervals.

verified against NARR over CONUS 1985-2012.

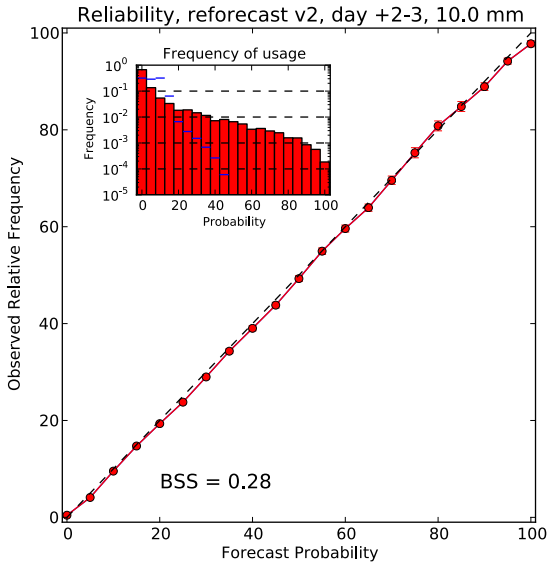
Reliability, > 10 mm precipitation 24 h^{-1}

Version 2 (2012 GEFS)

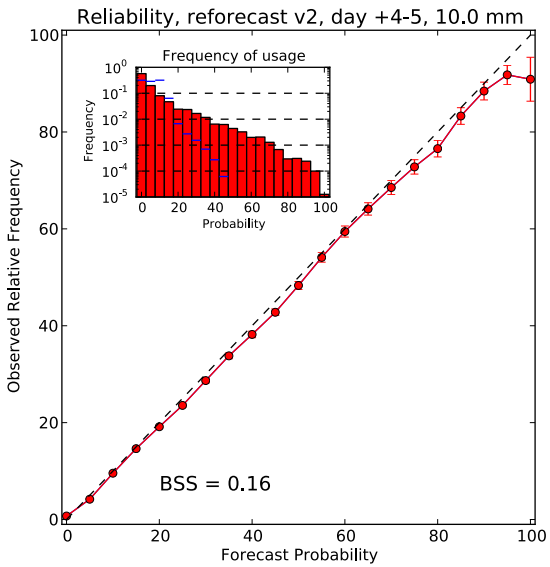
Day +0-1



Day +2-3



Day +4-5

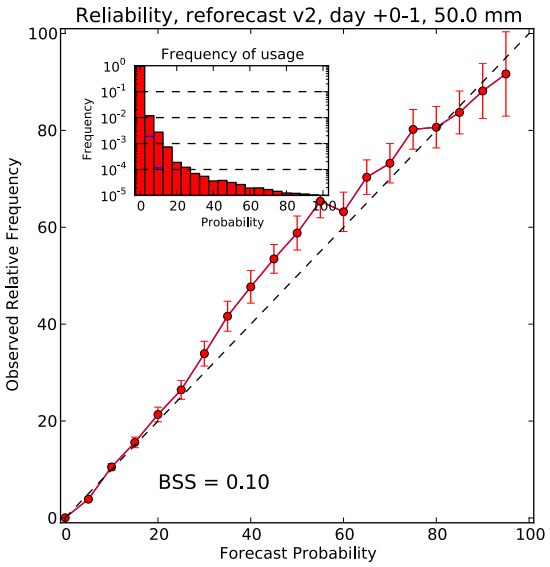


Almost perfect reliability.

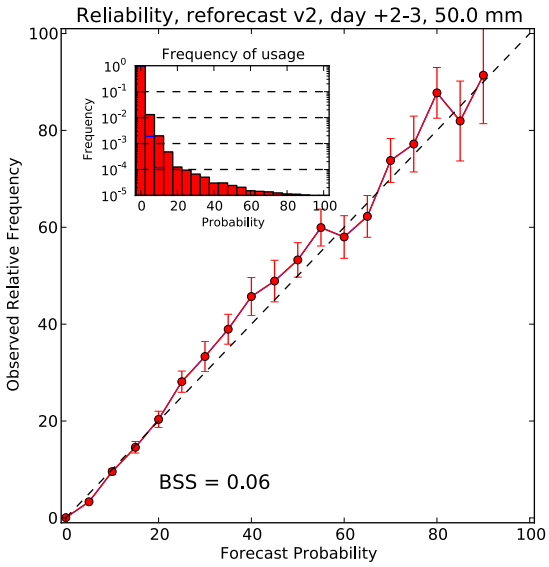
Reliability, > 50 mm precipitation 24 h^{-1}

Version 2 (2012 GEFS)

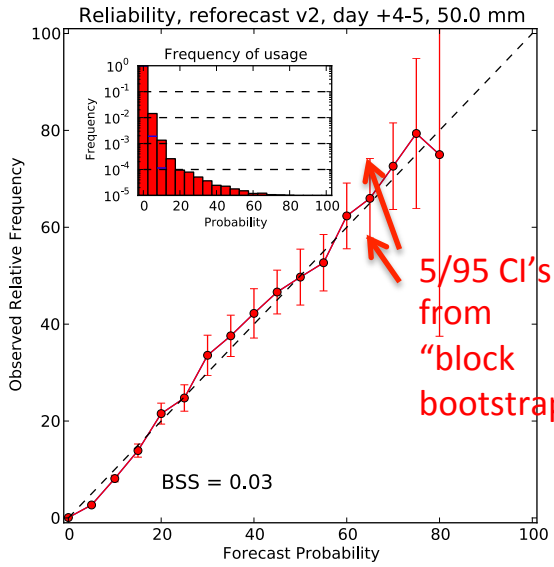
Day +0-1



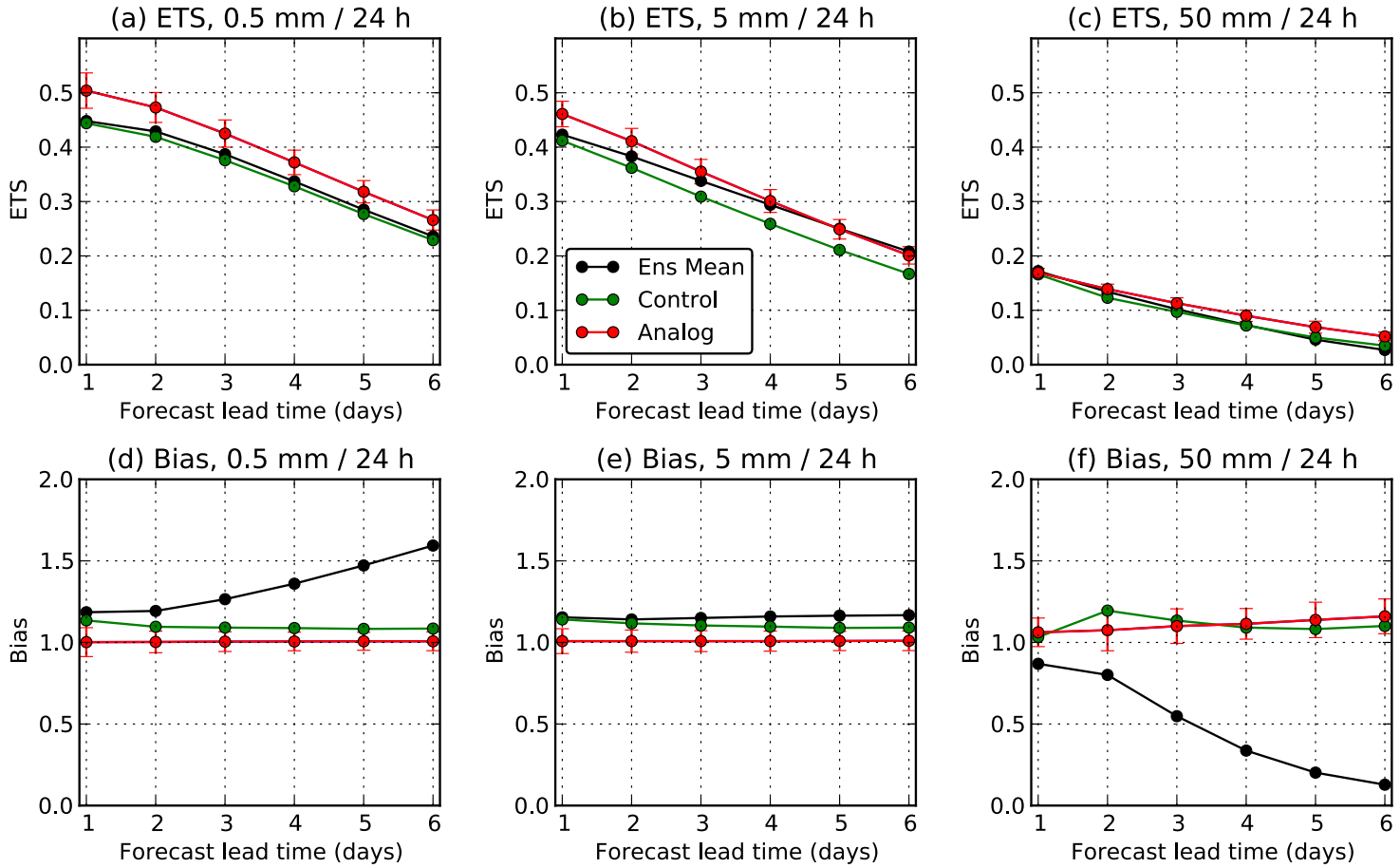
Day +2-3



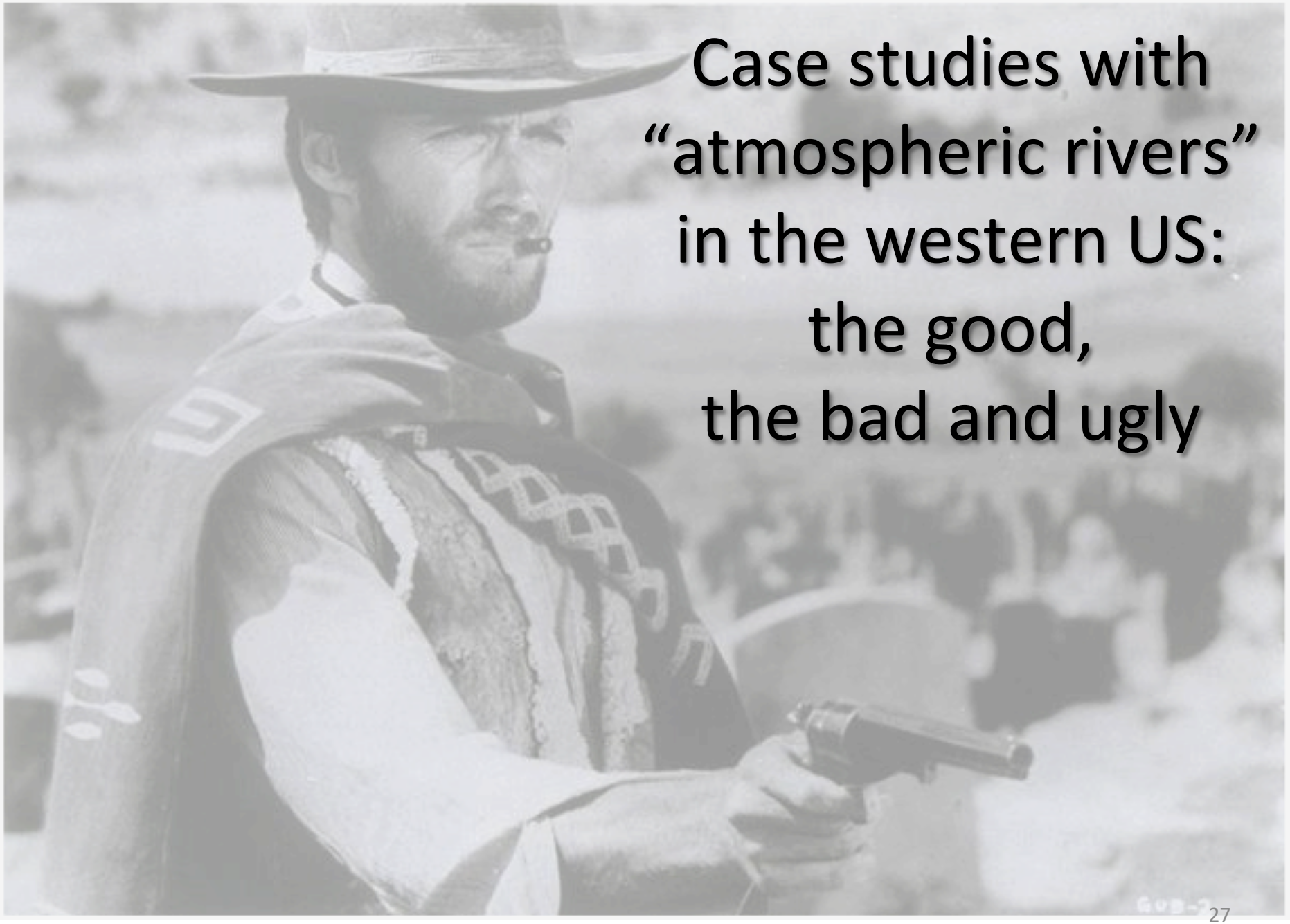
Day +4-5



Post-processing to improve deterministic forecasts

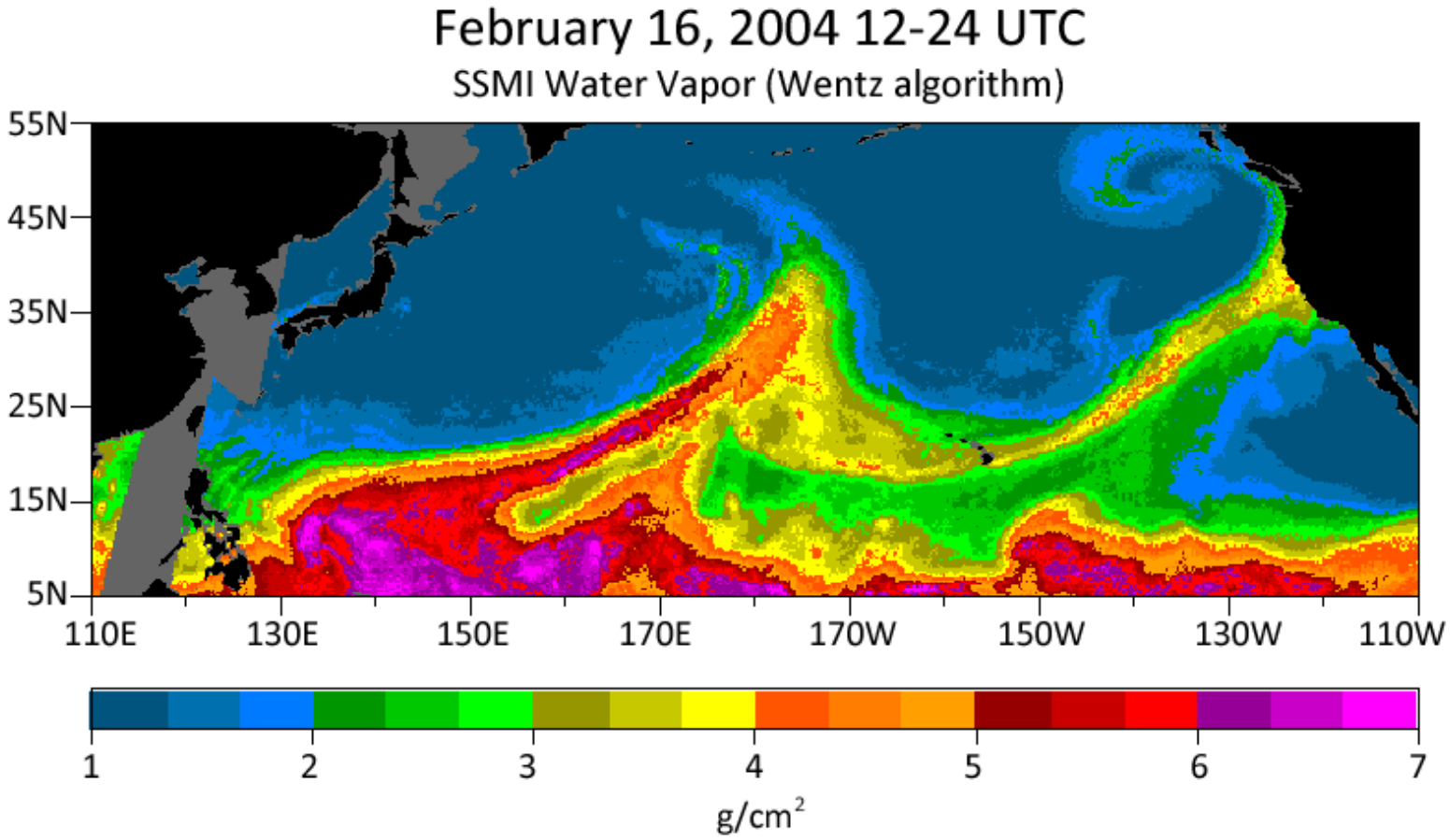


Some further modifications to analog technique, including Ebert's "probability-matched mean" approach allow post-processed forecasts to improve significantly on deterministic forecast guidance supplied by the model.



Case studies with "atmospheric rivers" in the western US: the good, the bad and ugly

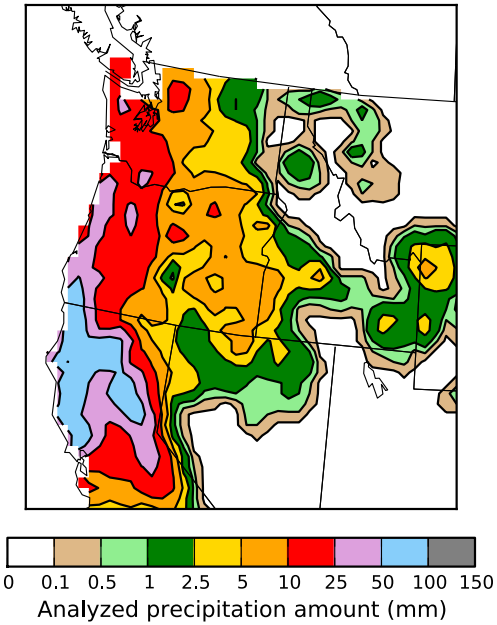
The bad and ugly atmospheric rivers case study



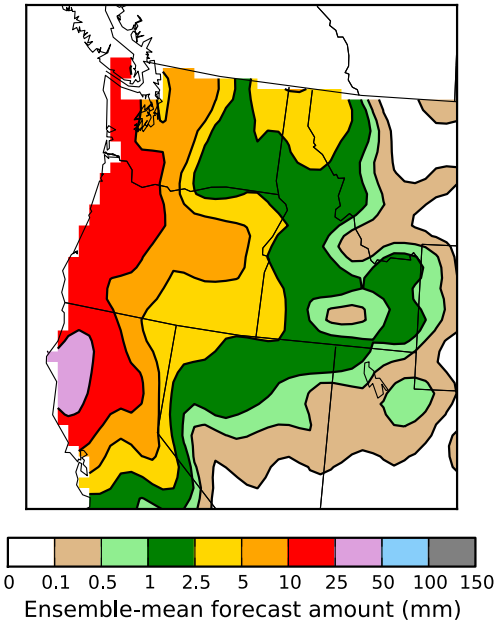
➢ 10” rain in the coastal mountains, 4-7” in Russian River watershed. Streamflows in top 0.2% of historical observations.

Source: http://www.esrl.noaa.gov/psd/atmrivers/events/

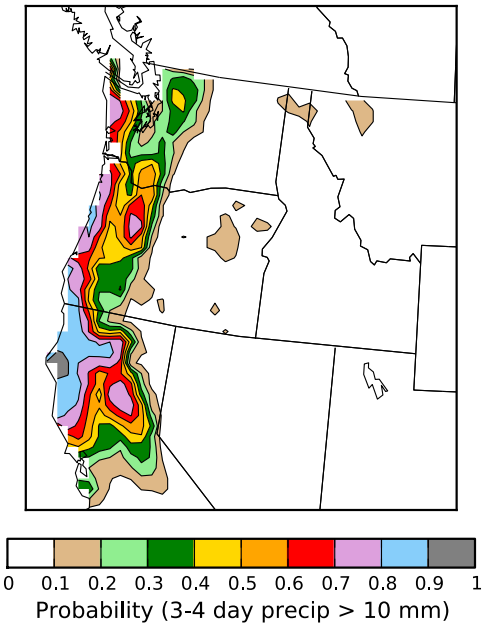
(a) 24-h accumulated precip analysis, VT = 2004021700



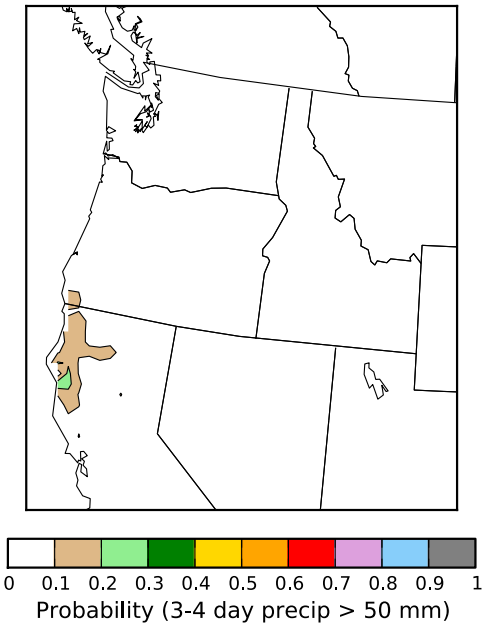
(b) 3-4 day mean forecast, Reforecast v2, VT =2004021700



(c) P(3-4 day accum precip > 10 mm), Reforecast v2, VT = 2004021700

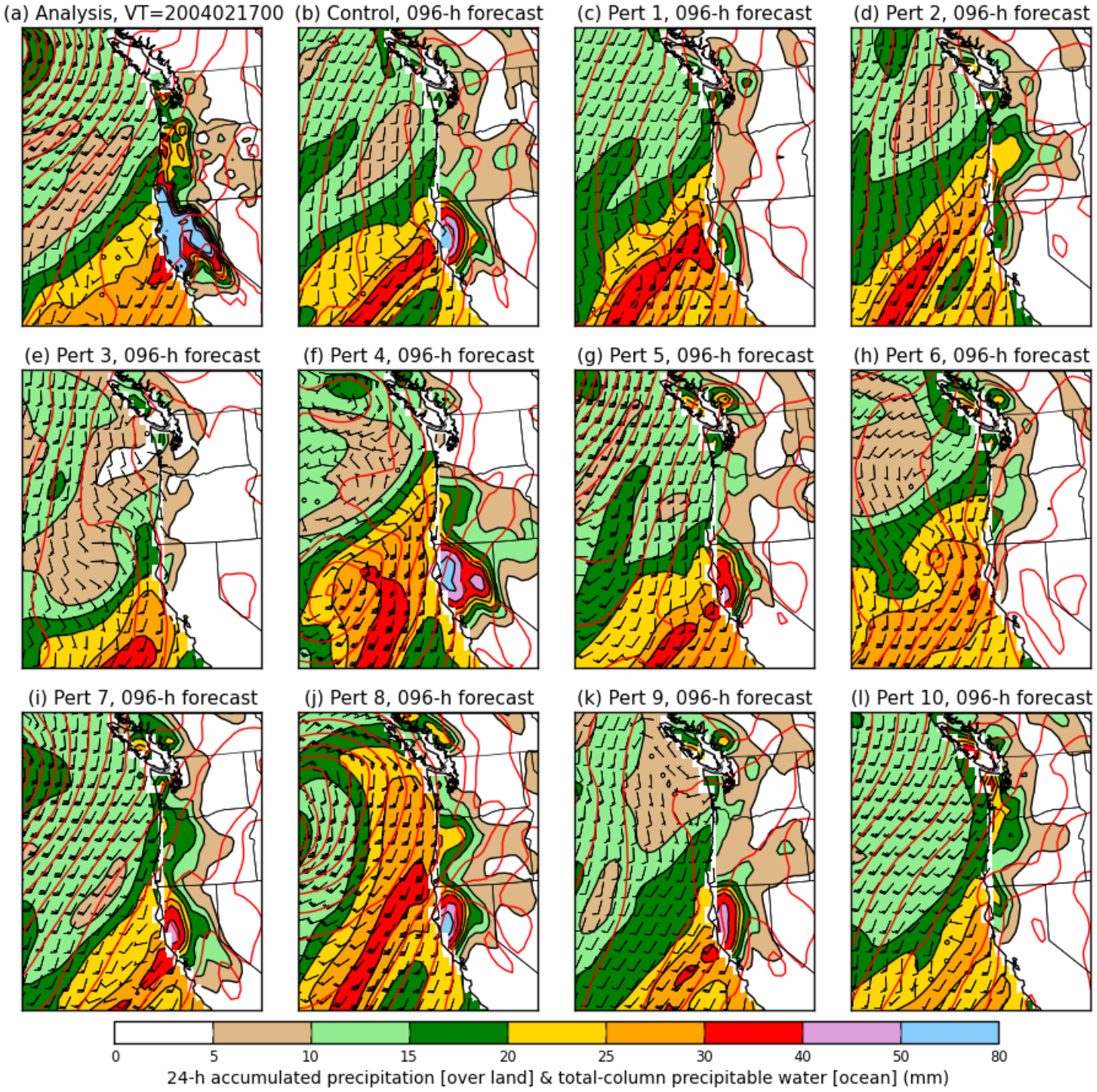


(d) P(3-4 day accum precip > 50 mm), Reforecast v2, VT = 2004021700



+4-day forecast

very little hint of excessive rainfall in post-processed guidance over N CA.



+4-day forecast

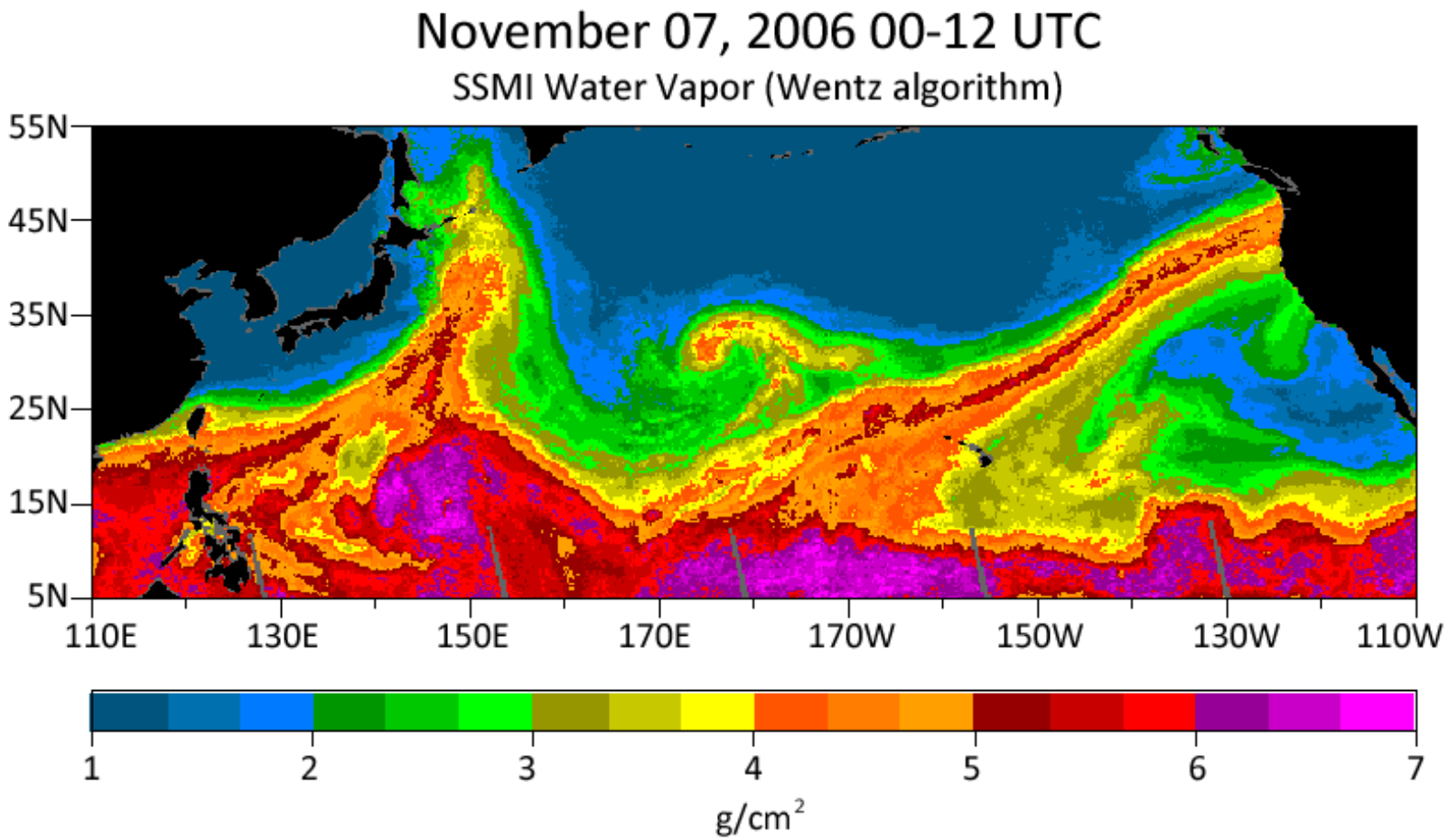
Colors: over the ocean, the total-column precipitable water. Over land, the 24-h accum. precipitation.

Wind barbs for the 925 hPa level.

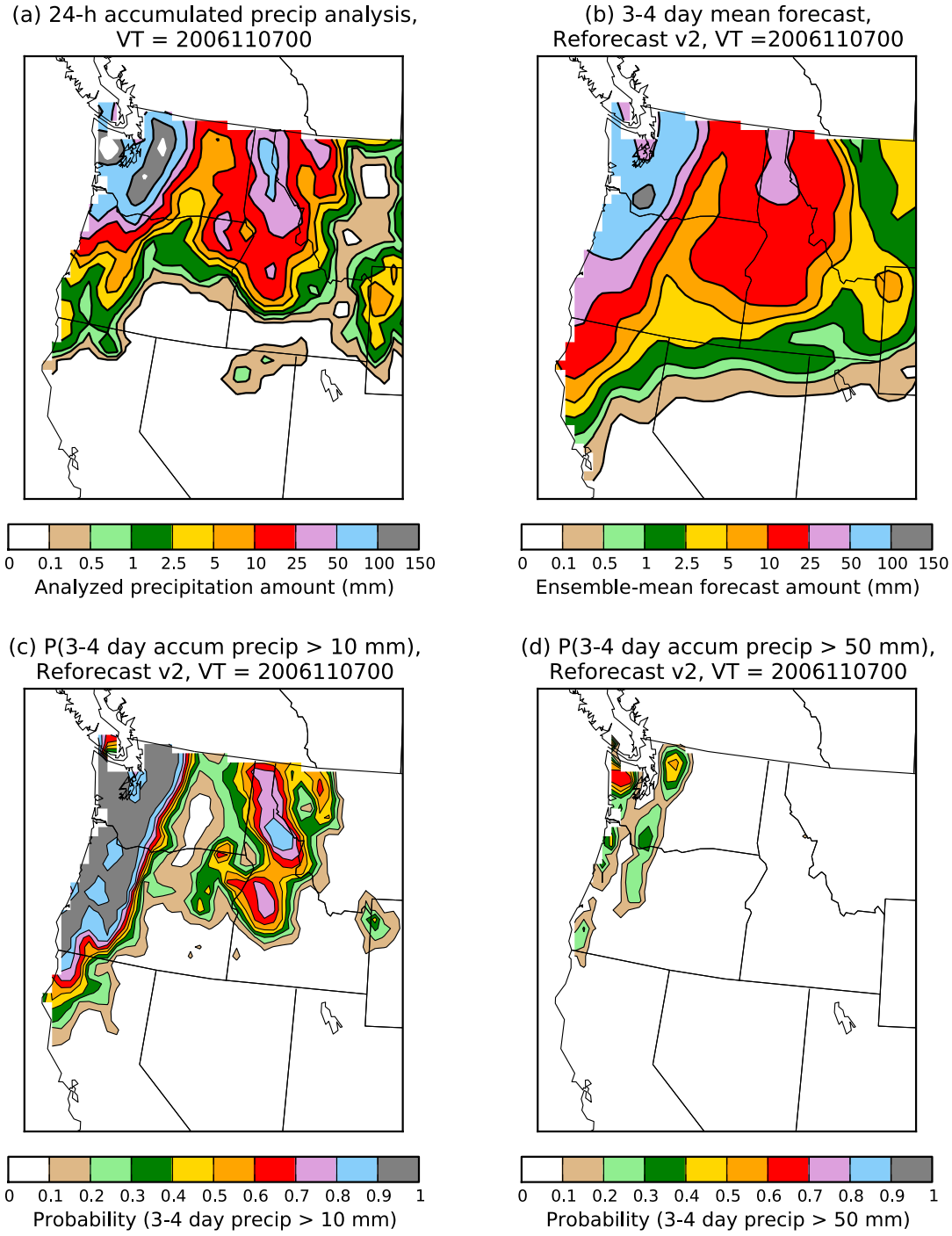
Red contours: mean sea-level pressure.

Lesson: garbage in, garbage out.

The “good” atmospheric rivers case study:
Nov 2006 Oregon-Washington floods

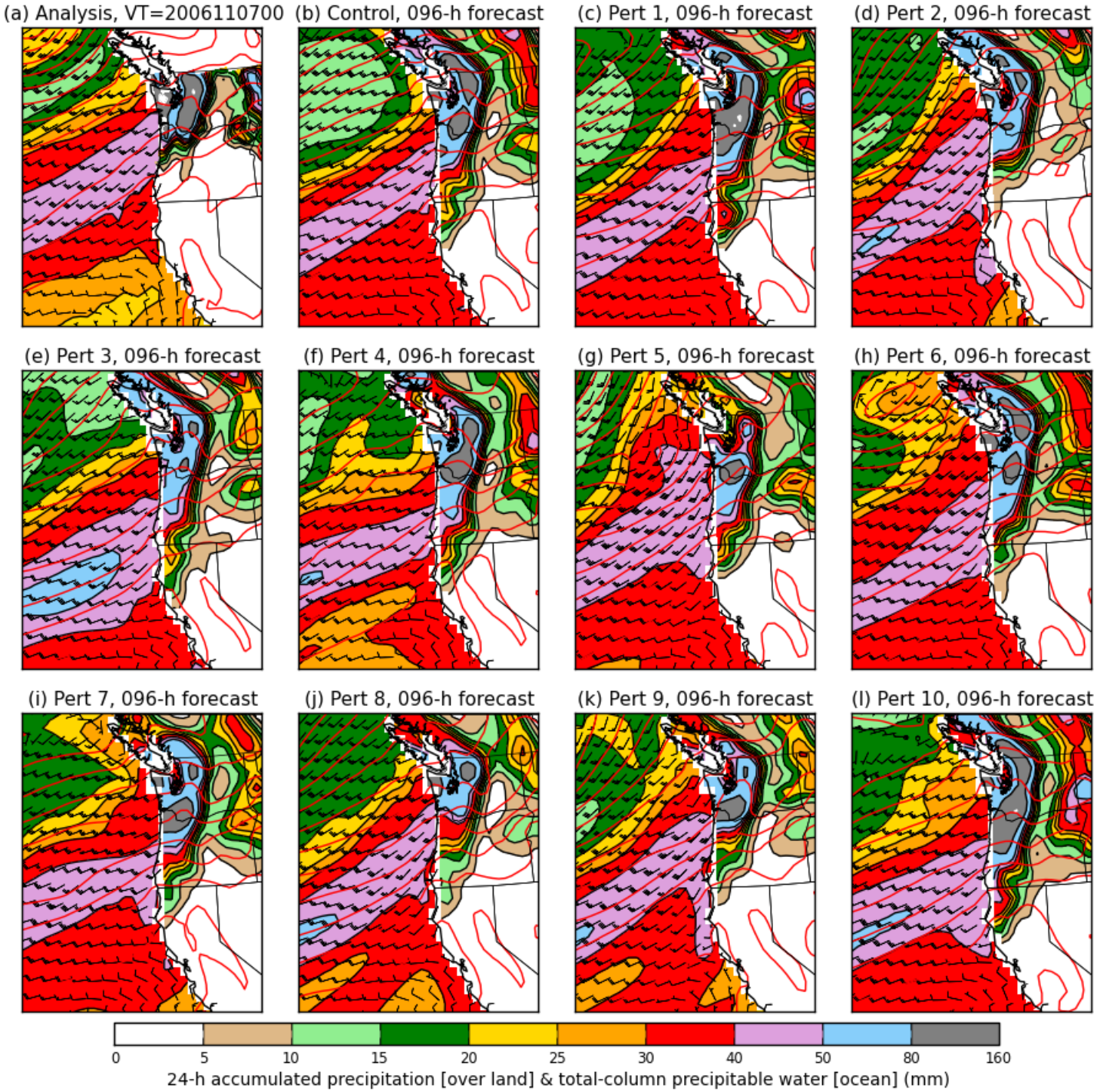


8-20 inches of rain in Cascades; flooded rivers; extensive damage to Mt. Rainier NP.



+4-day forecast

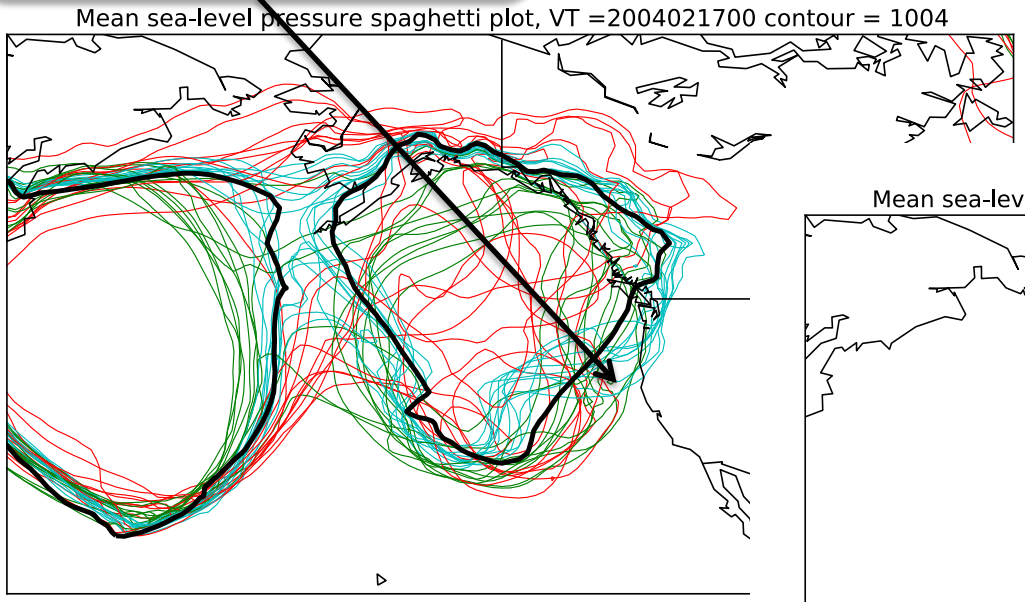
Now there are reasonably high probabilities of heavy precipitation.



+4-day forecast

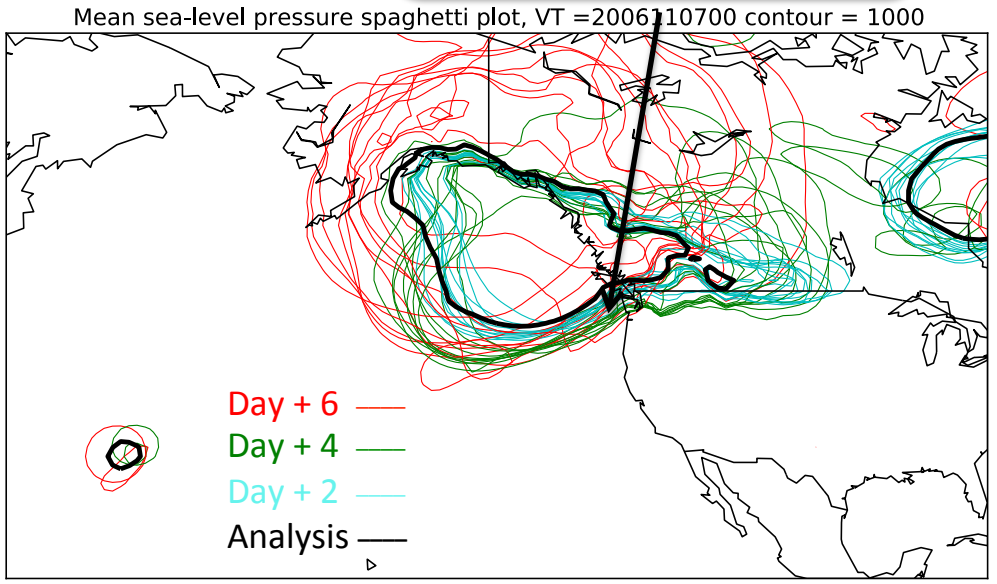
Spaghetti Westerns

Inconsistent forecasts of orientation of isobars and hence wind direction



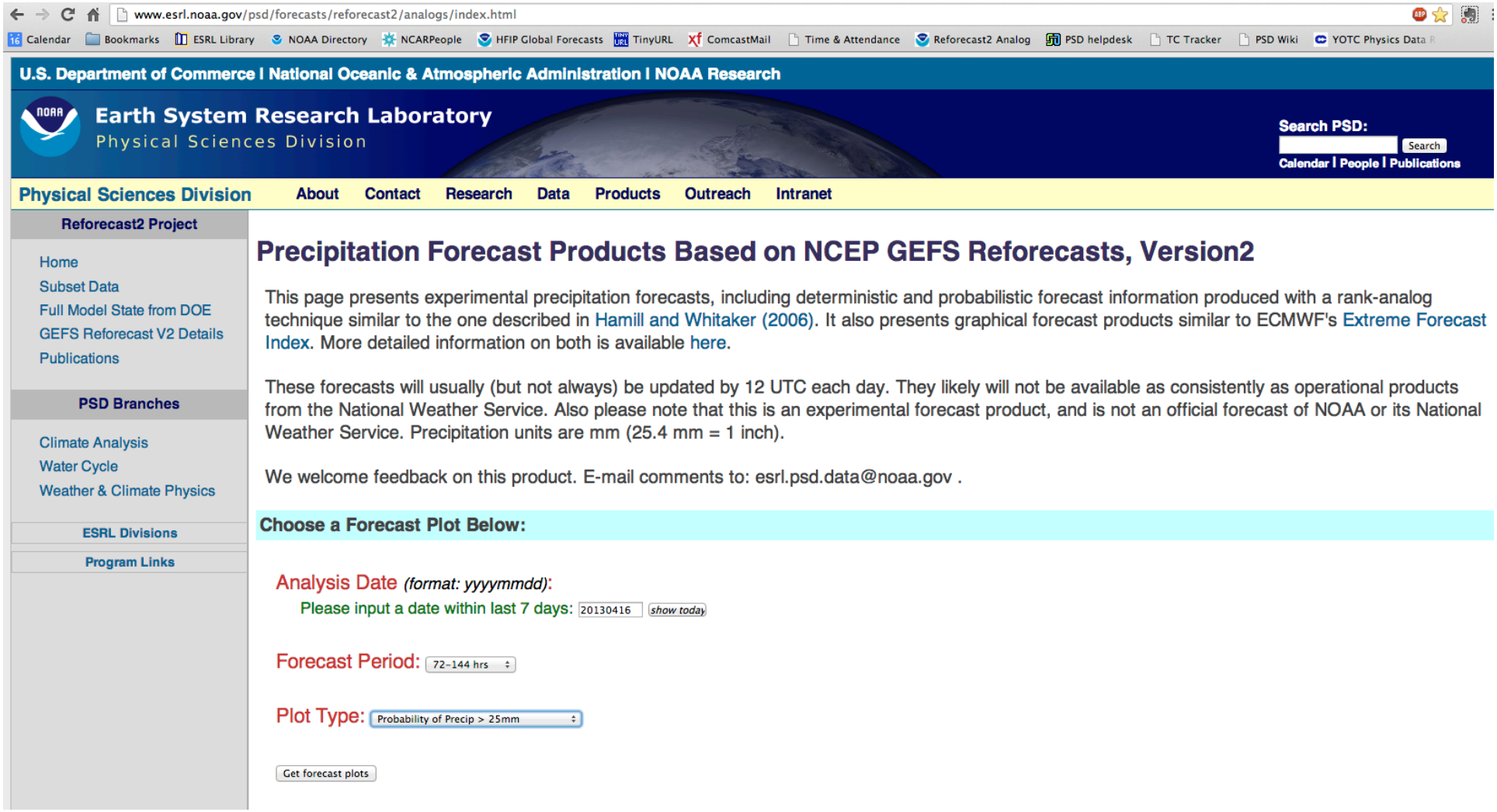
The bad and the ugly

Consistent forecasts of orientation of isobars and hence wind direction



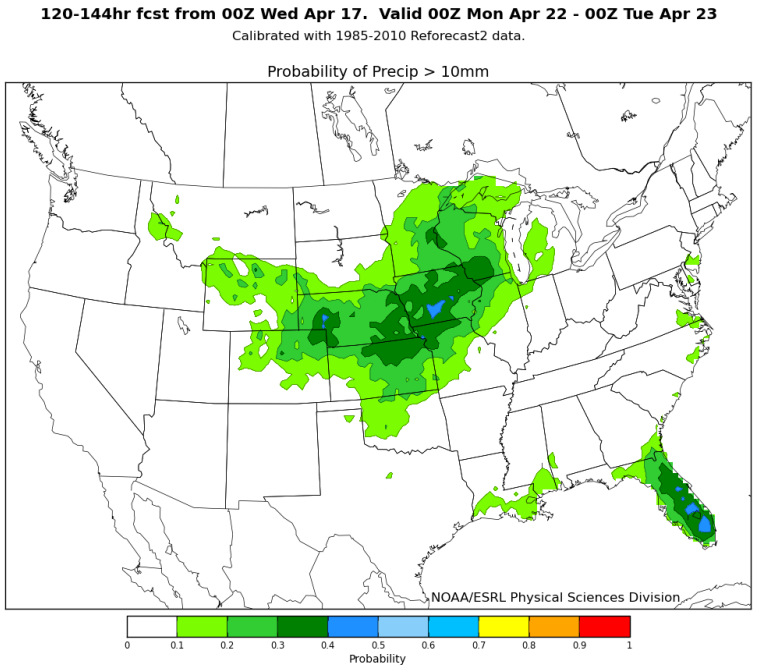
The good

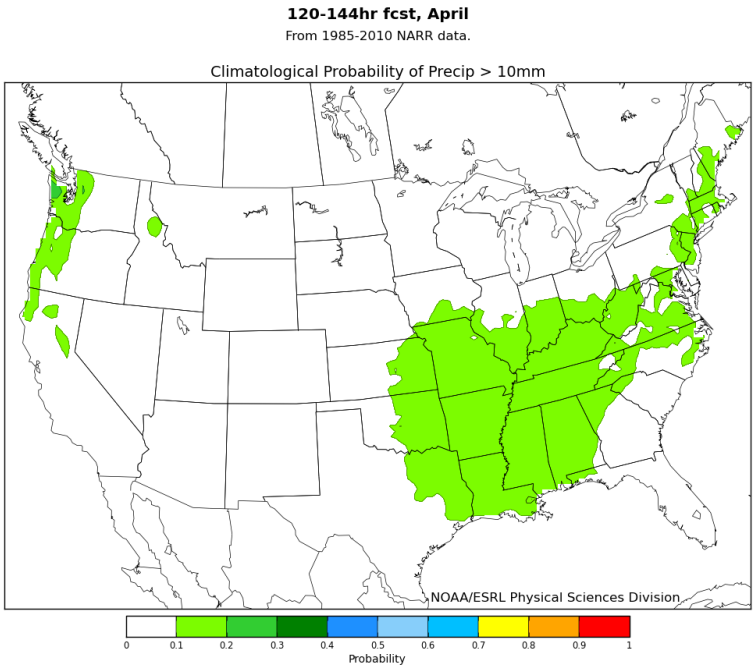
Reforecast precipitation product web page



http://www.esrl.noaa.gov/psd/forecasts/reforecast2/analogs/index.html)

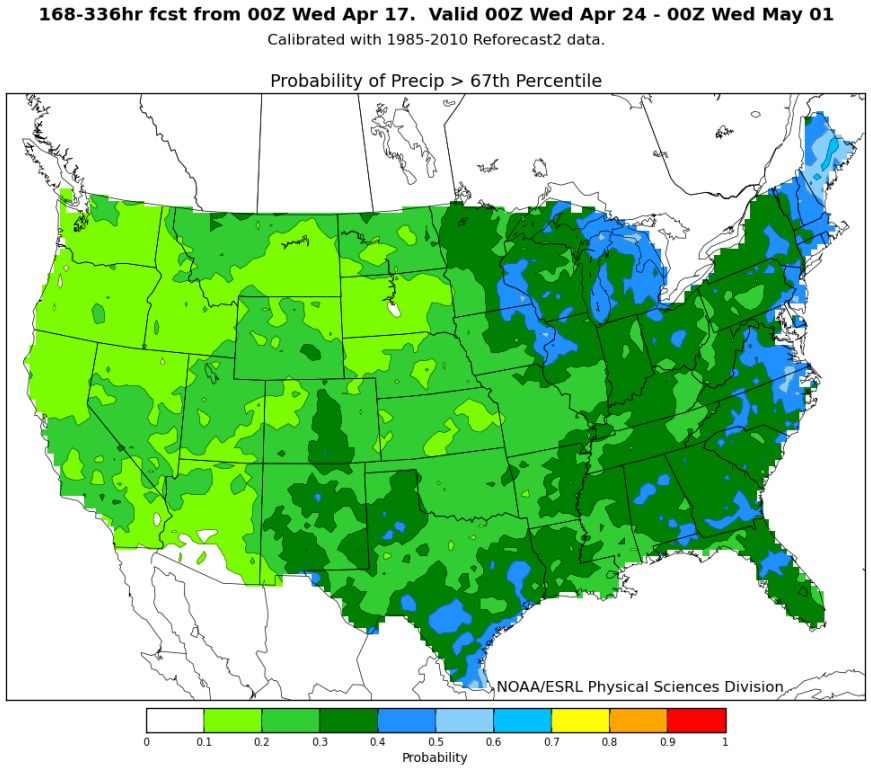
Probability of > 25 mm, 72-144 h forecast from 00Z Tuesday, 17 April 2013

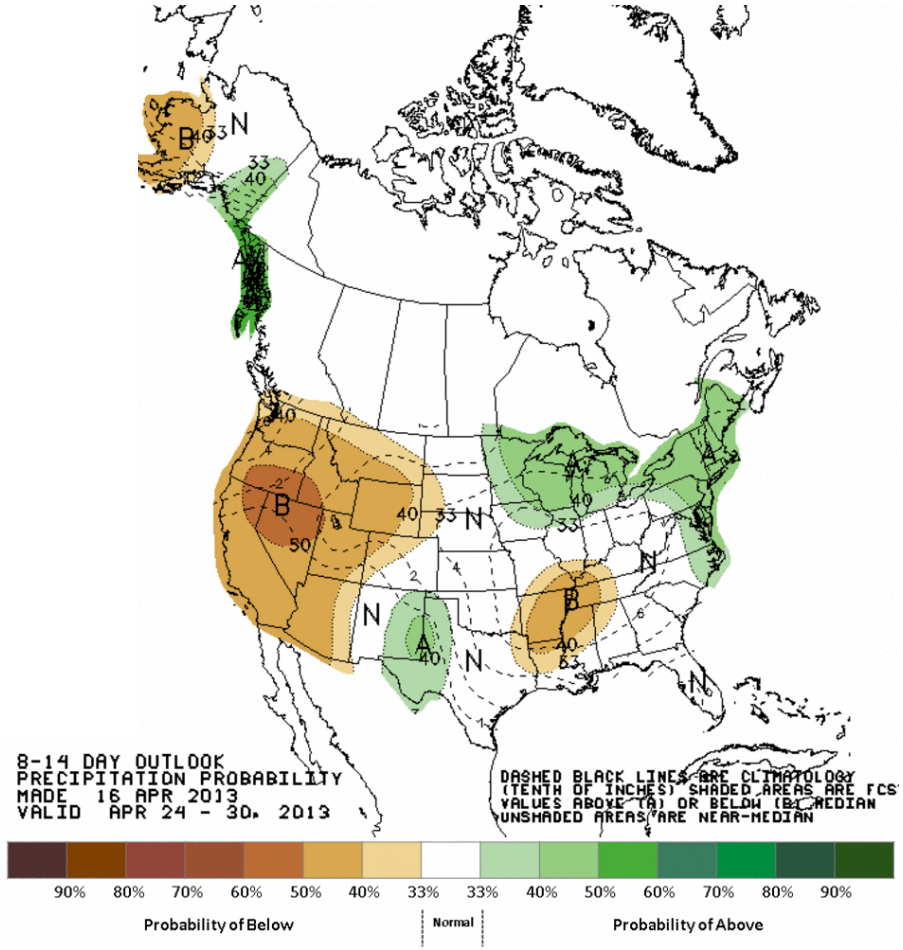




http://www.esrl.noaa.gov/psd/forecasts/reforecast2/analogs/index.html)

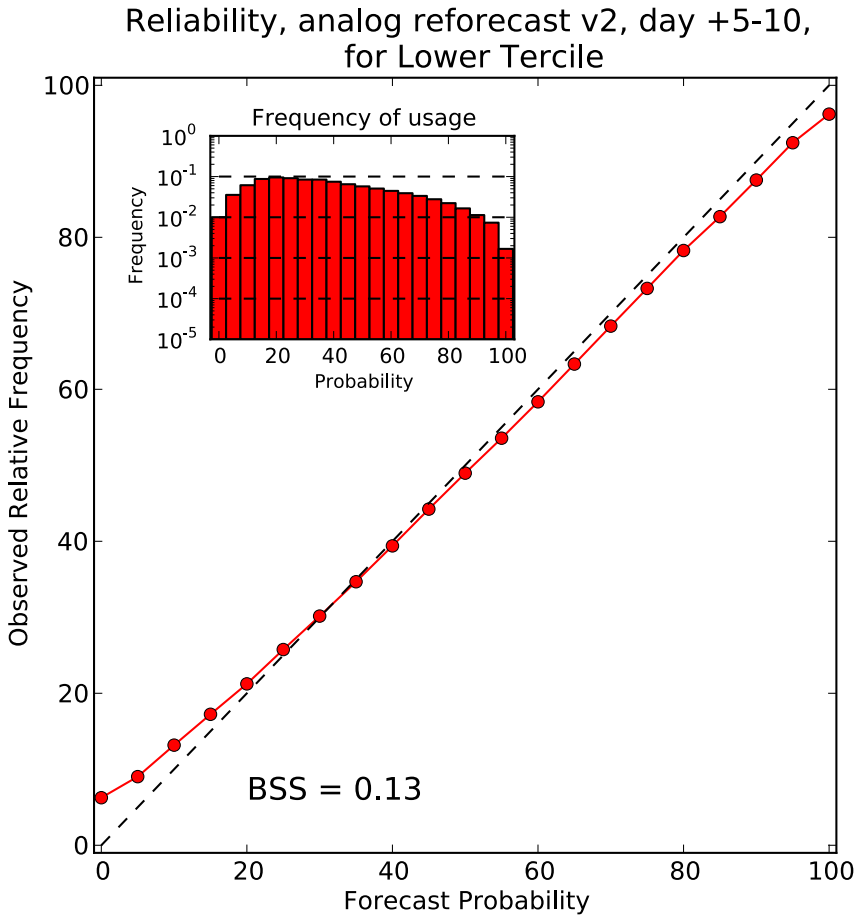
Week-2 forecast, P(precip > upper tercile)

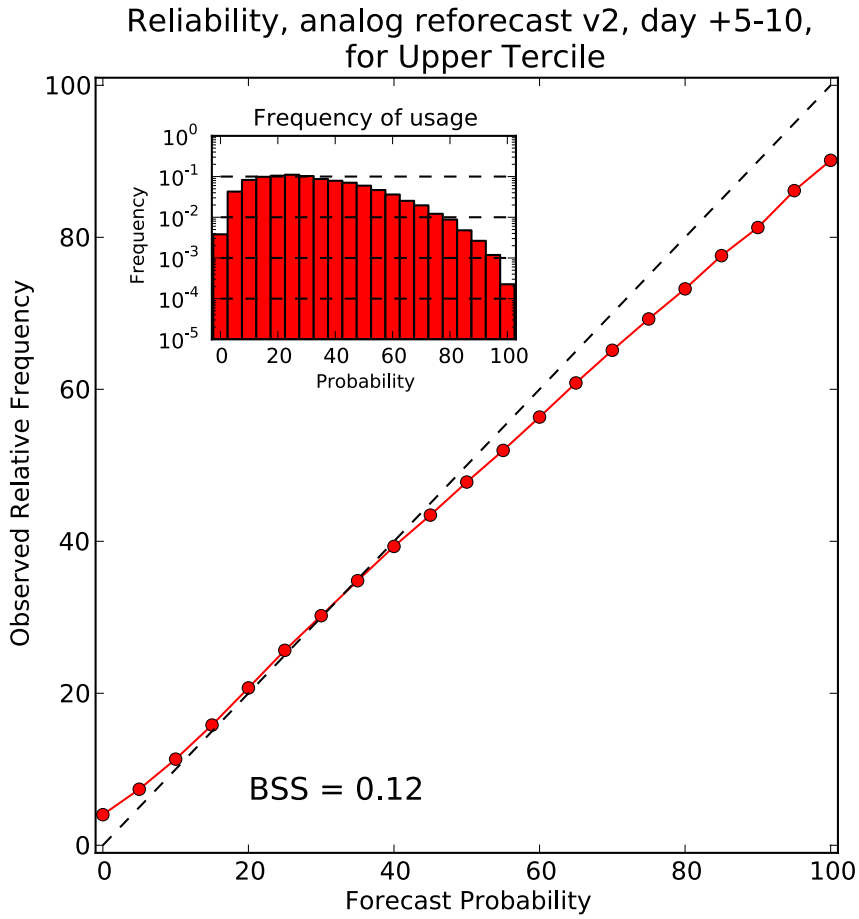




Note: times don't match up exactly here; CPC created during the day yesterday, ours created overnight.

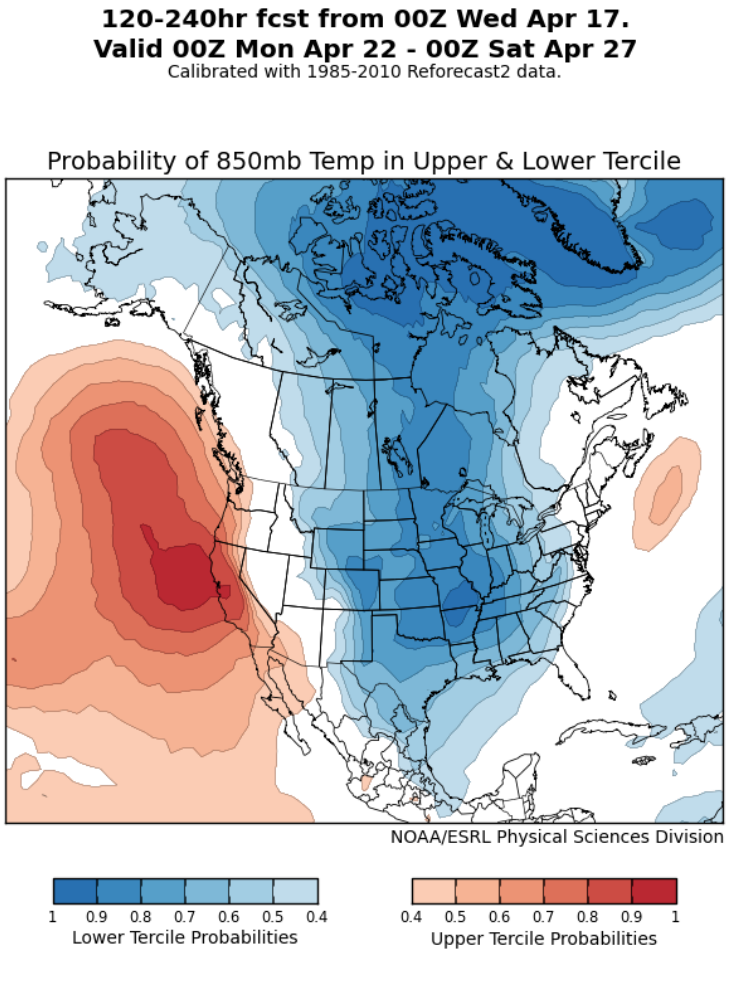
Post-processed precipitation reliability, upper and lower tercile, days 5-10 (120-240 h lead)

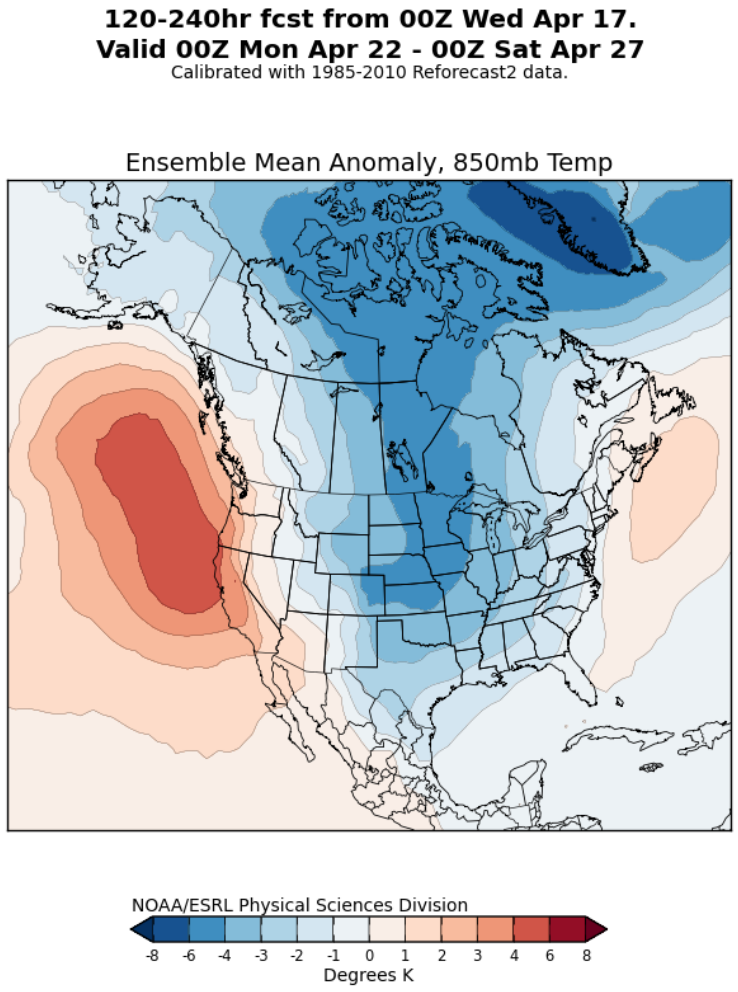




Comparatively, in our 2004 MWR article, for version-1 reforecasts validated against station data, 6-10 day RPS skill was ~ 0.06.

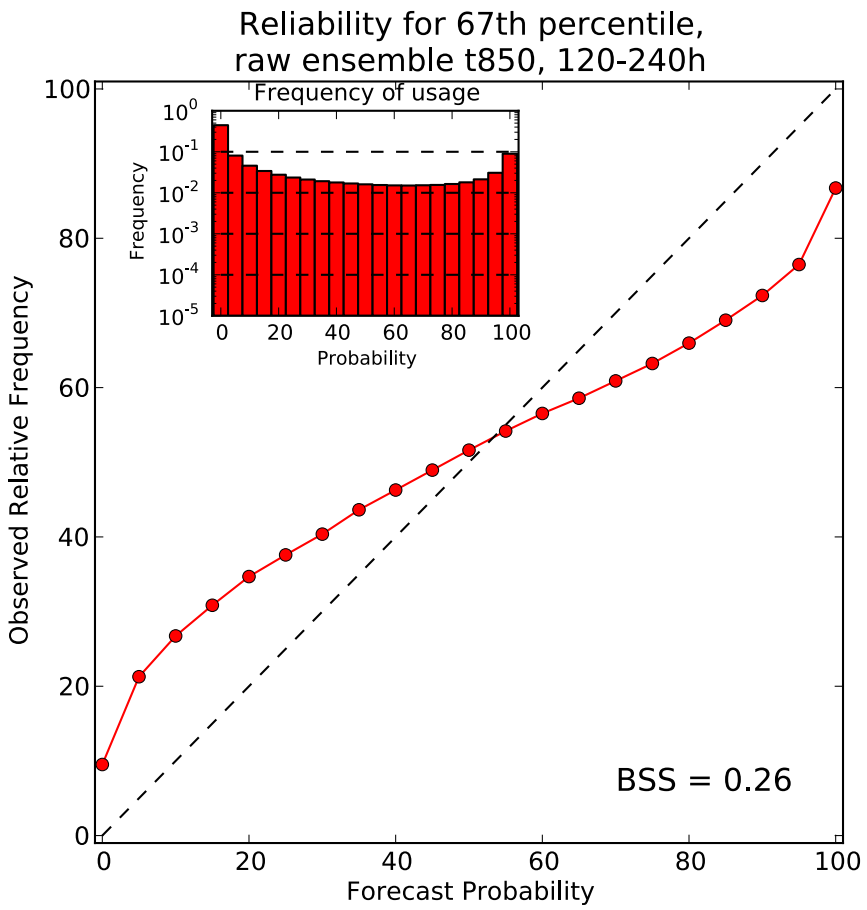
Also: T2m, T850, Z500 calibrated forecast information

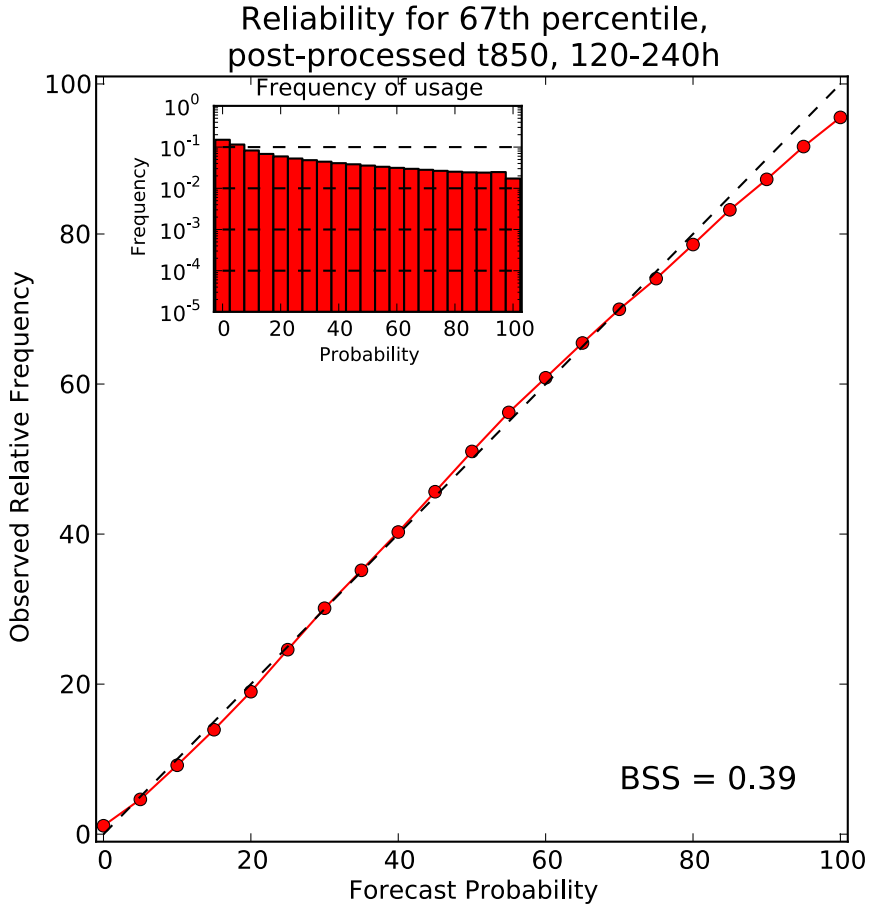




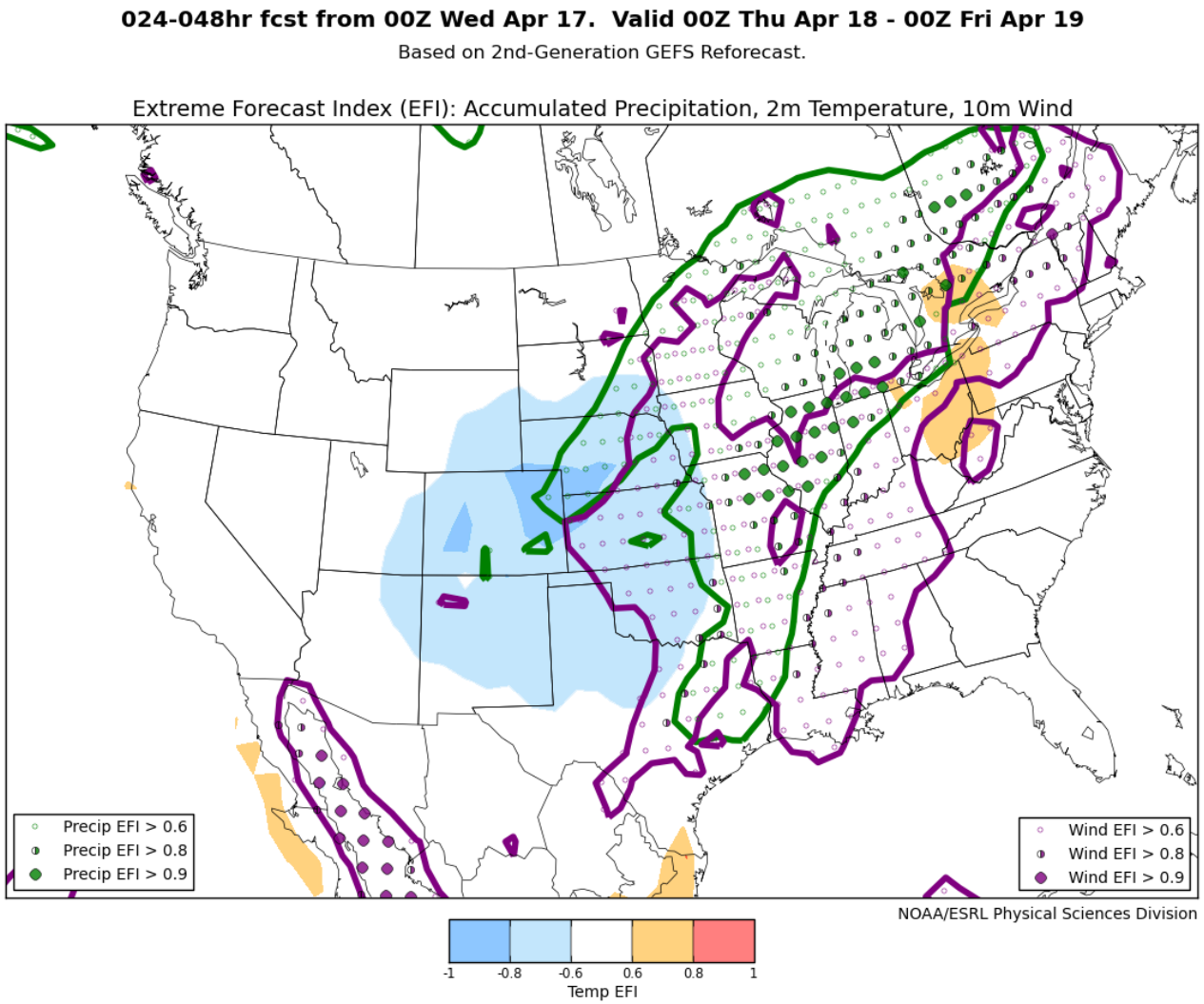
http://www.esrl.noaa.gov/psd/forecasts/reforecast2/medrange/index.html

T850 reliability, upper tercile





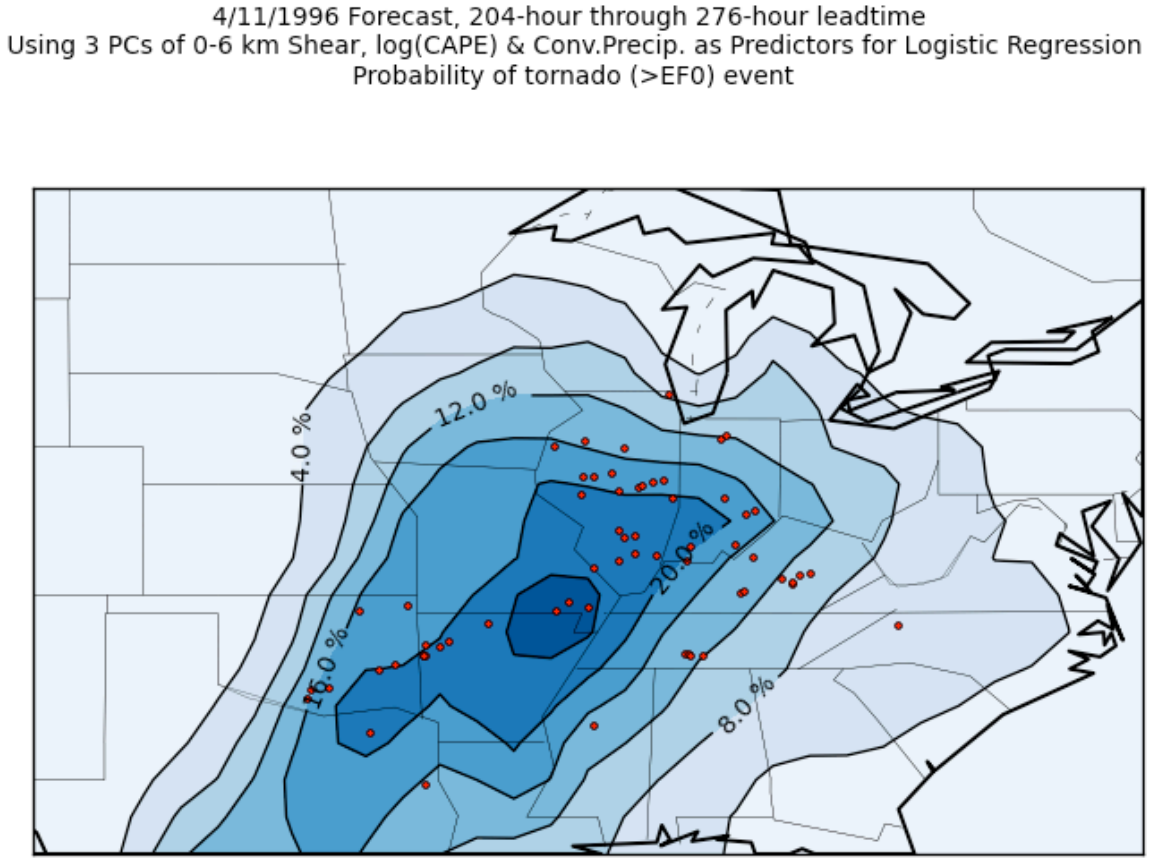
Extreme forecast index (following ECMWF)



In the absence of observations or analyses for verification, the EFI can at least provide you with a heads-up of where the GEFS is unusual relative to its own model climatology for that time of the year.

(also available from http://www.esrl.noaa.gov/psd/forecasts/reforecast2/analogs/index.html)

Research application: extended-range tornado forecasting



Francisco Alvarez,
St. Louis University,
is working with me
and others on using the
reforecasts to make
extended-range
predictions of
tornado probabilities.

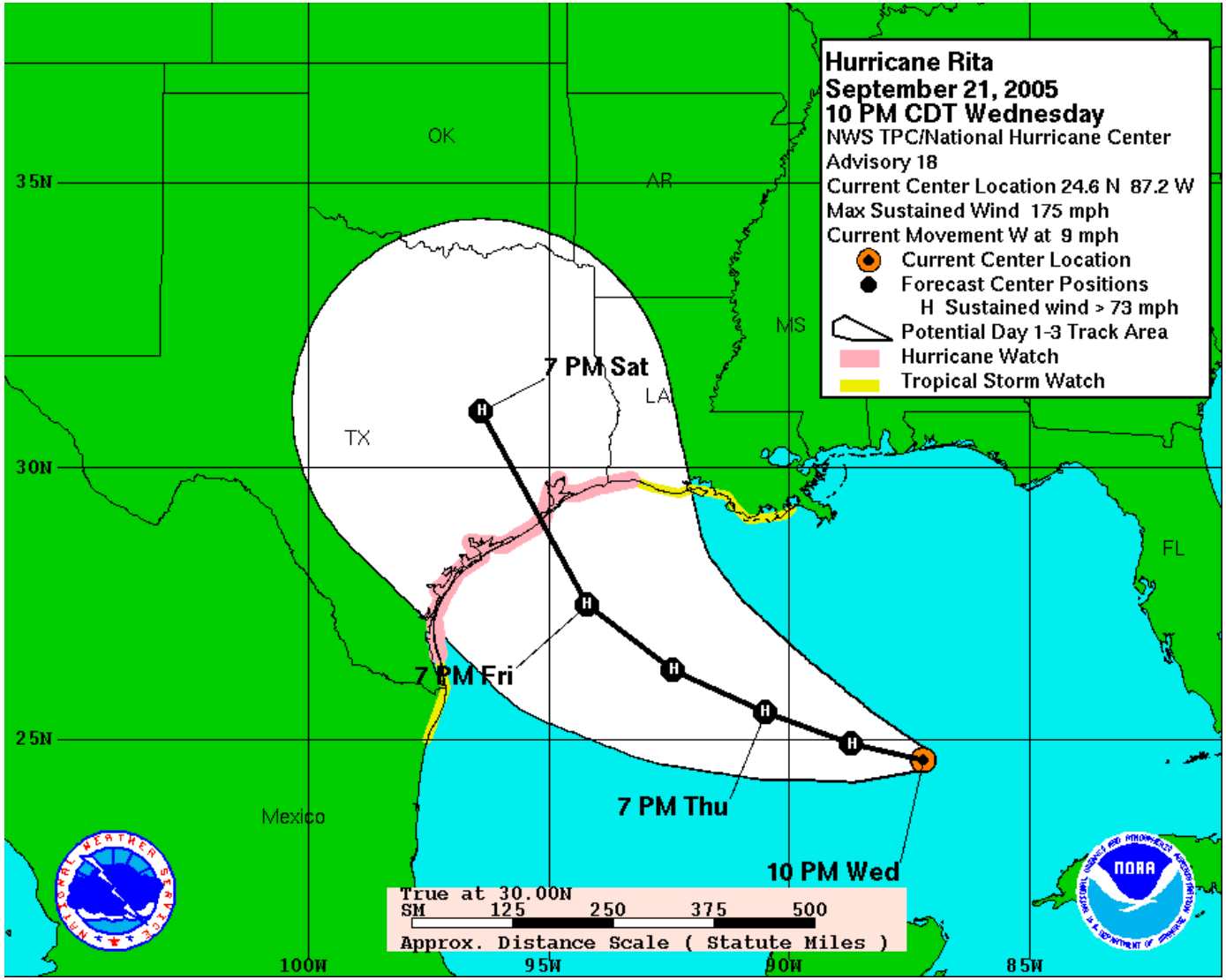
Ph.D. work,
in progress.

Demo: Regional reforecast with WRF ARW v3.4 using global reforecast for initial, boundary conditions

- 2-way nested simulation 36-, 12- and 4-km with 36 vertical levels
  - 12- and 4-km moving nests
- Time step: 180, 60, and 20 s
- Initial and boundary condition: GFS reforecast ensemble member
- Tiedtke cumulus scheme on 36 and 12 km; explicit on 4 km
- YSU PBL scheme
- HYCOM ocean analysis
- WSM6 microphysics
- Noah land surface
- 2D Smagorinsky turbulence scheme
- Goddard shortwave radiation
- RRTM longwave radiation
- Second order diffusion
- Positive definite scalar advection
- Donelan wind-dependent drag formulation
- Garratt wind-dependent enthalpy surface fluxes

c/o Tom Galarneau, NCAR & NOAA HFIP grant

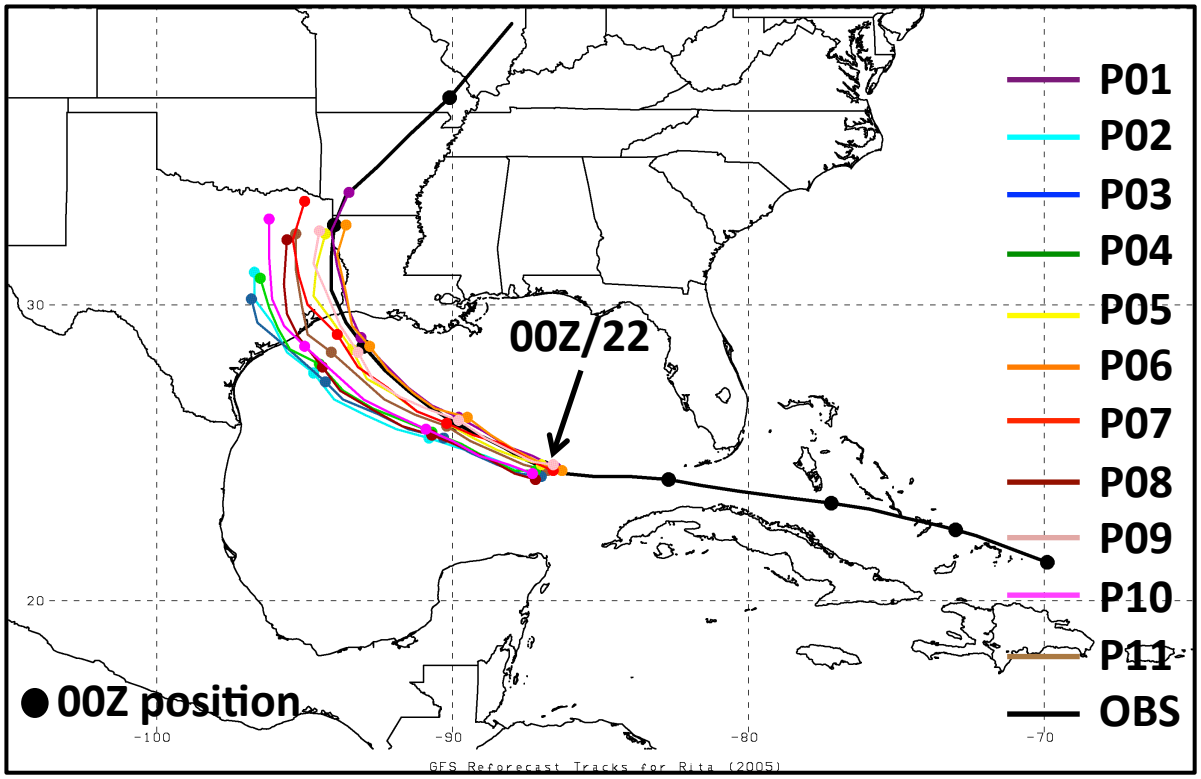
2005 Rita official forecast (Houston, TX evacuated)

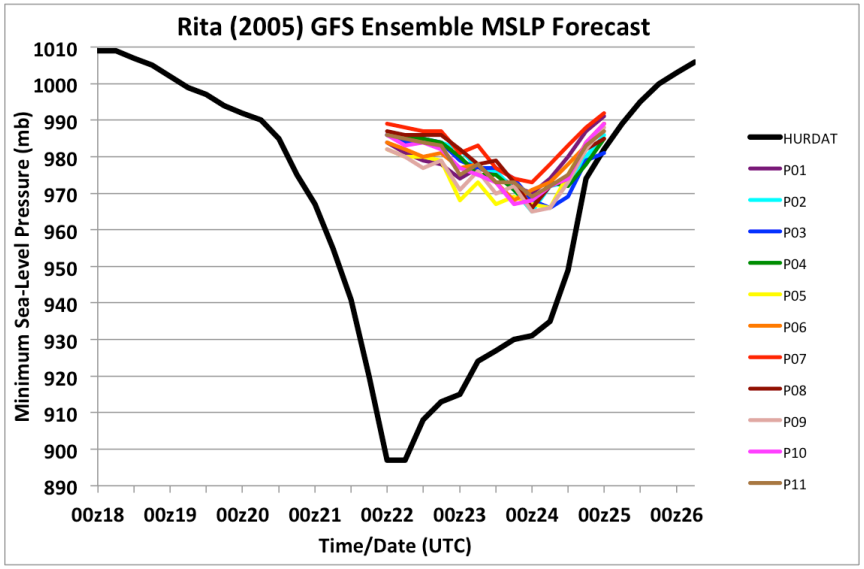


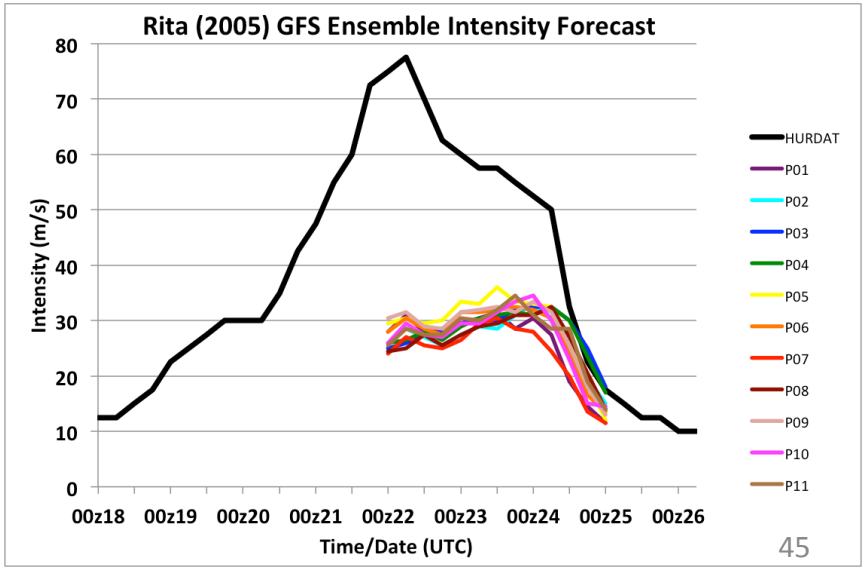
TC Rita (2005)

GFS reforecast ensemble

72-h forecast initialized at 00Z 22 Sept



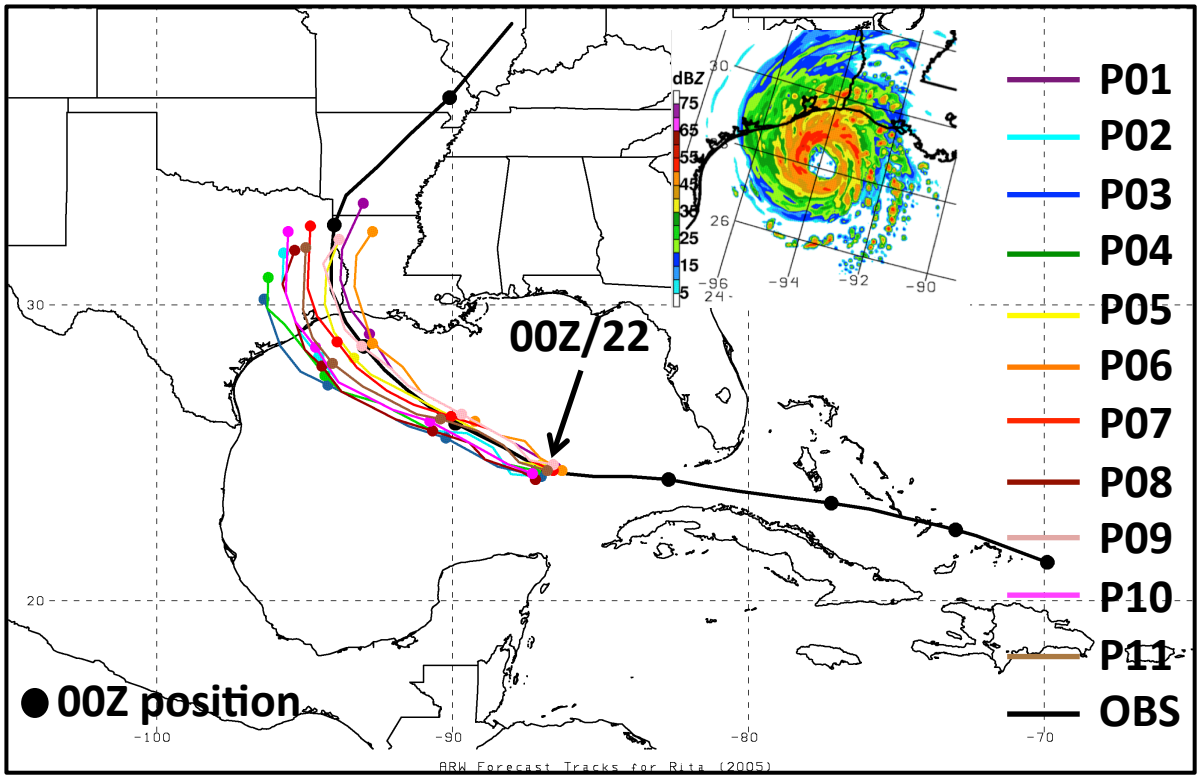


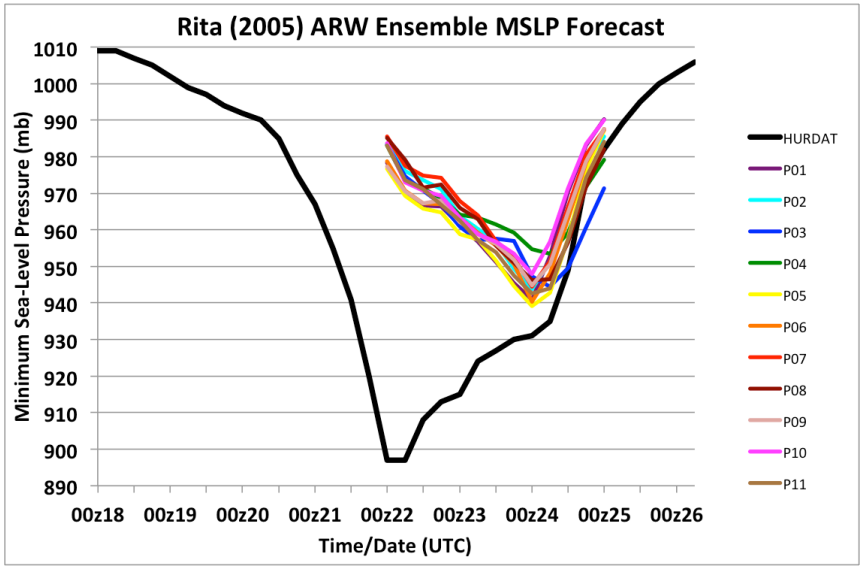


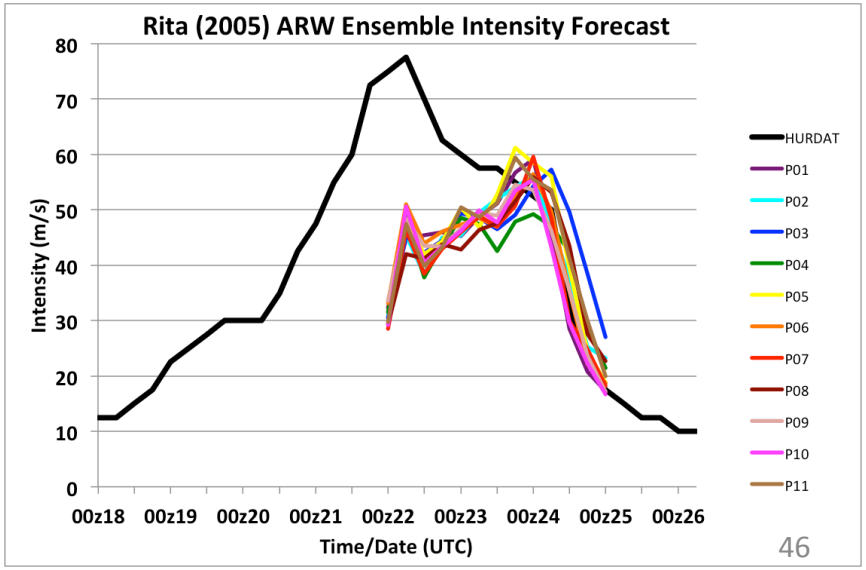
TC Rita (2005)

ARW ensemble with GFS reforecast ensemble as boundary and initial conditions

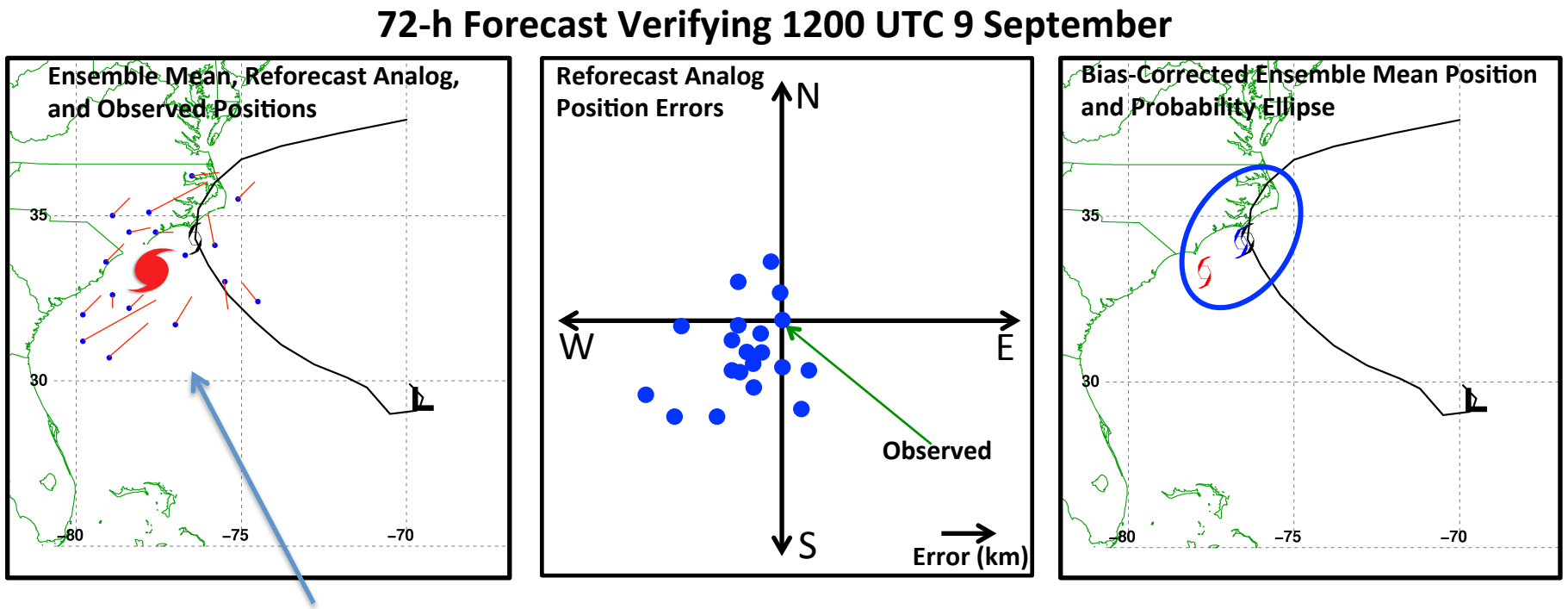
72-h forecast initialized at 00Z 22 Sept







A synthetic example of using reforecasts to make track error bias corrections



Red : mean forecast position

Blue dot: forecast positions of +72-h forecast analogs

End of red tail ___ : observed positions at +72 h

Conclusions

- Multi-decadal ensemble reforecast data set was created for current operational NCEP GEFS (circa 2012); useful for statistical calibration, regional reforecasting, understanding model biases, and much more.
- Reforecast and real-time forecasts data available now.
- Experimental forecast products available.
- We welcome your feedback on products, problems to esrl.psd.reforecast2@noaa.gov.
- If you find these reforecast products valuable, please communicate that to NCEP/EMC . They need to make decisions about whether & how to conduct reforecasts in the future on their operational system.
- An article on the data set and its applications is in press at BAMS,

  http://journals.ametsoc.org/doi/pdf/10.1175/BAMS-D-12-00014.1